MIT'S MAGAZINE OF INNOVATION

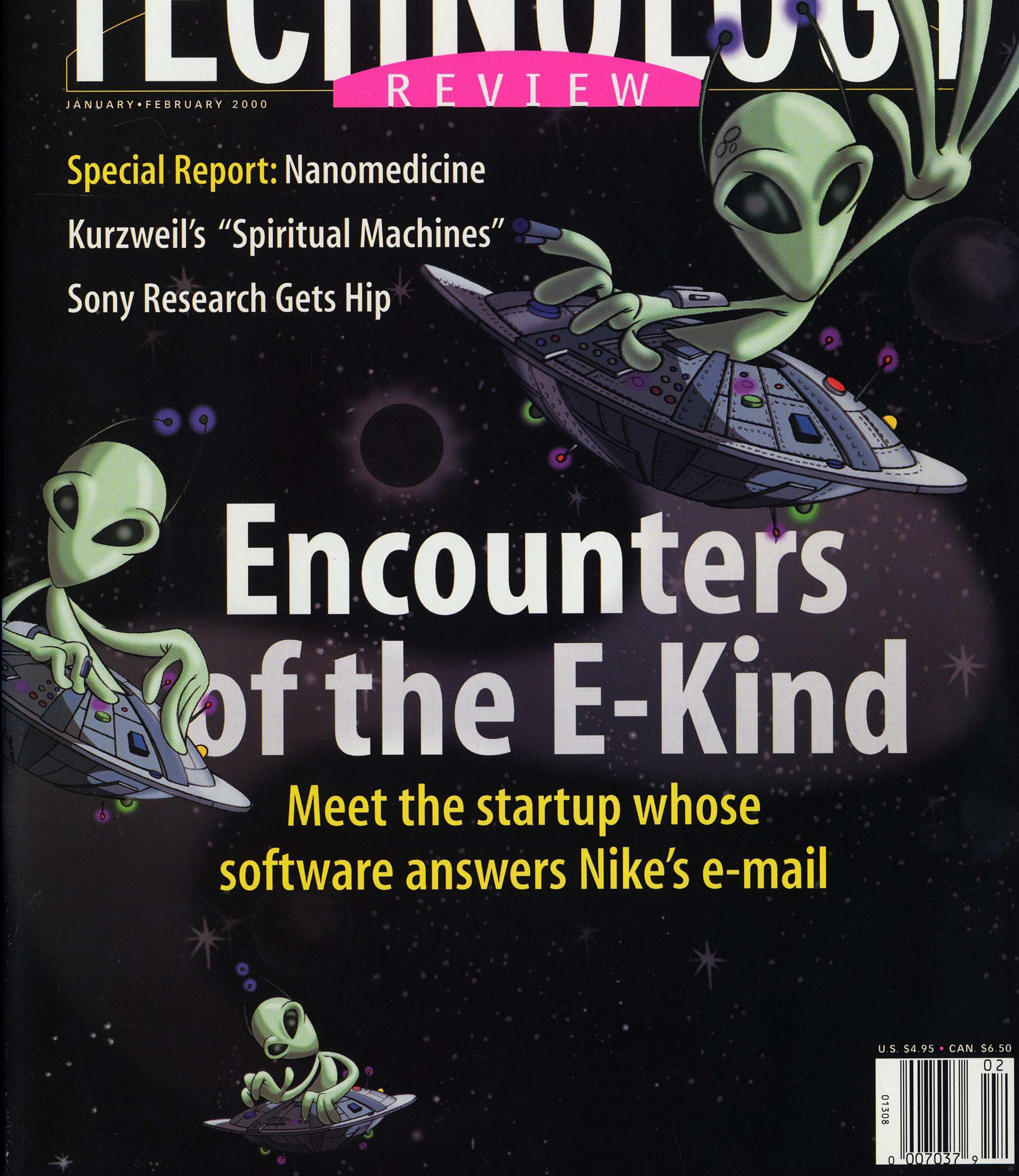
TECHNOLOGY REVIEW

JANUARY•FEBRUARY 2000

Special Report: Nanomedicine

Kurzweil's "Spiritual Machines"

Sony Research Gets Hip



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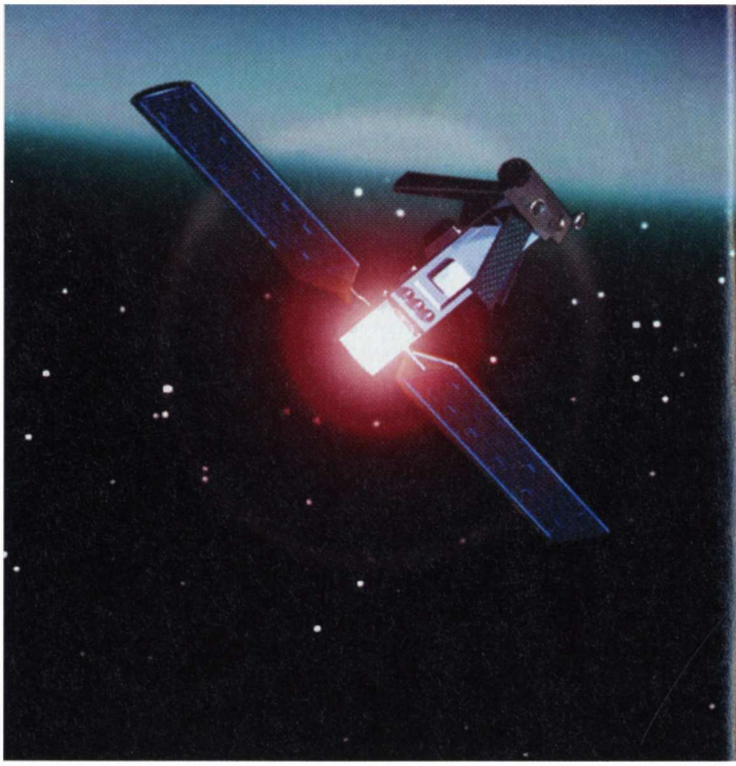
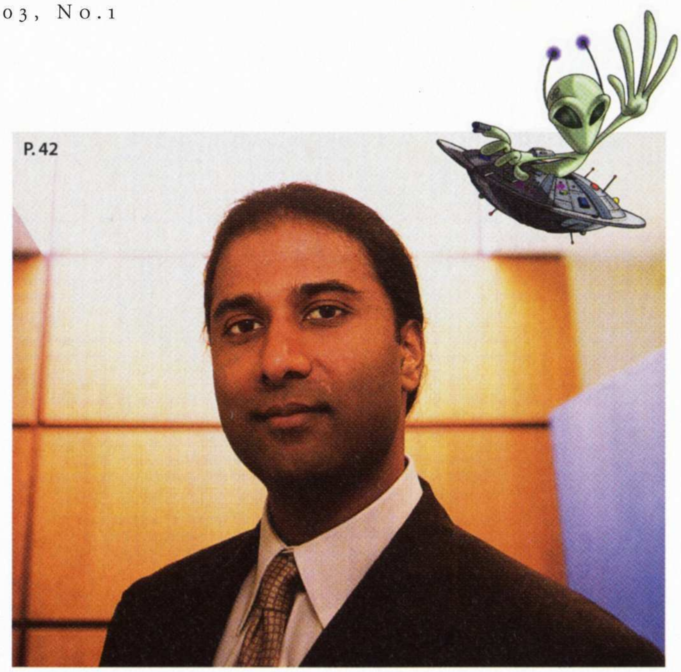


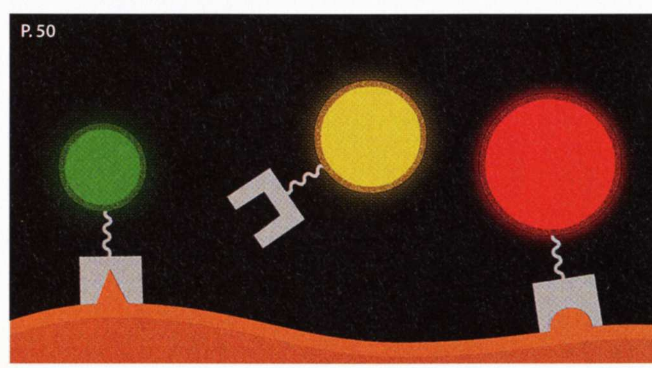
CONTENTS

TECHNOLOGY REVIEW *January/February 2000*

VOLUME 103, NO.1

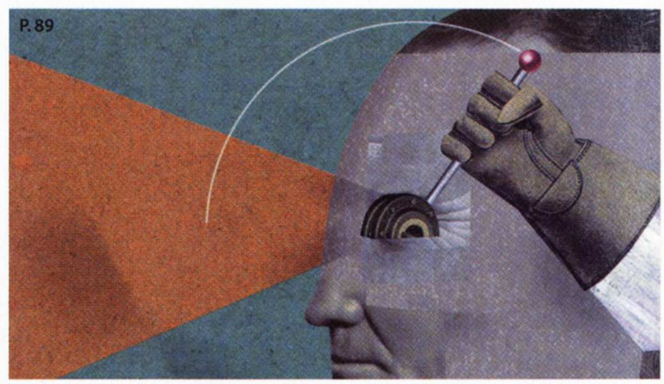
Features



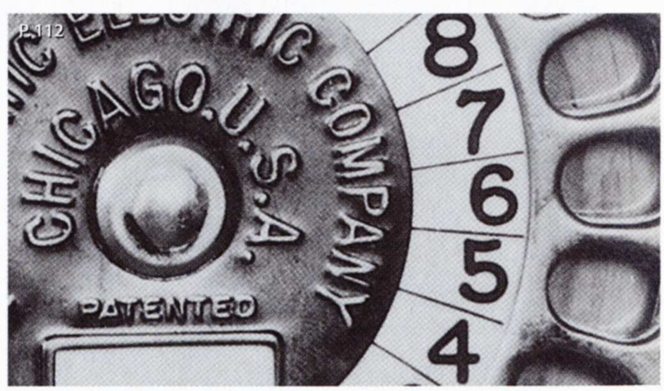


Cover illustration by Zoe Helene and Manoj Katoor, General Interactive

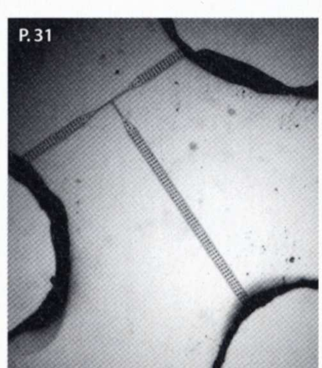
P. 89



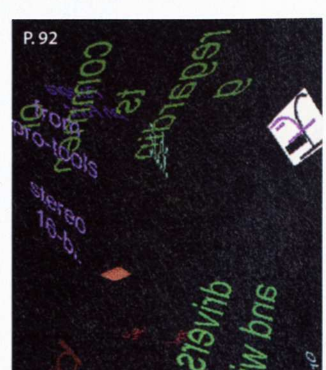
P. 112

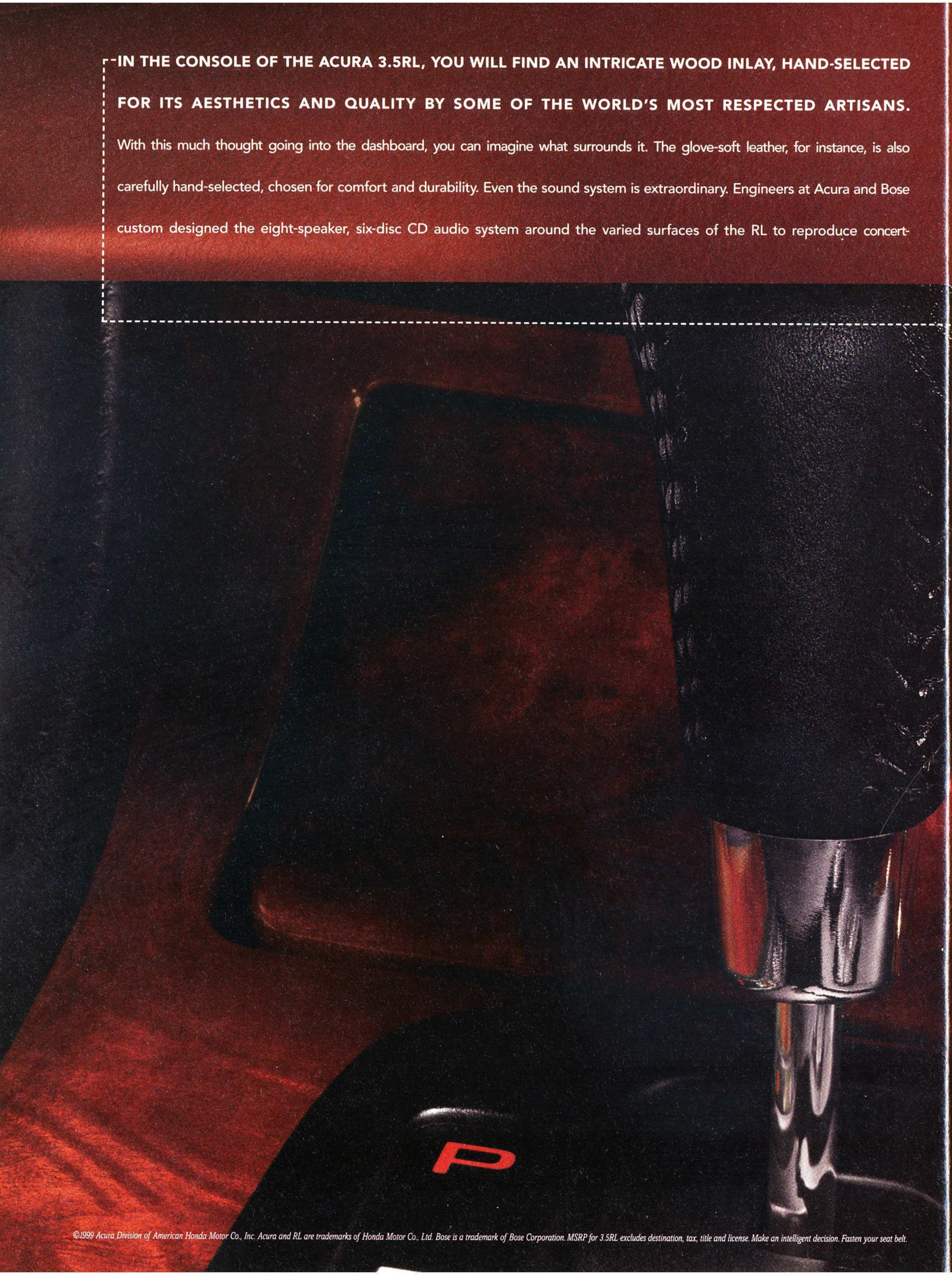


P. 31



P. 92

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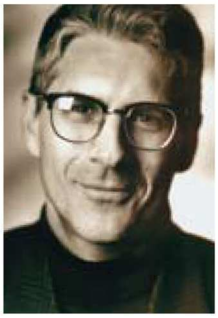
INDEX People and Organizations in Our Articles

Boundary Effects

THE SCALPEL IS A WONDROUSLY SIMPLE AND EFFECTIVE TOOL THAT HAS saved many lives. But from the vantage point of a human cell, a scalpel is about as precise as an incoming asteroid. The processes that constitute life and death, health and disease, occur within cells on the scale of billionths of a meter (nanometers). This is roughly the dimension of the DNA double helix, the proteins issuing from the genetic code, and all the other macromolecules that float in the aqueous environment of the living cell. The ultimate medical toolkit is not the scalpel and suturing needle; it is a set of tools small enough to go right inside the cell and repair individual DNA molecules or proteins the way a mechanic adjusts the timing belt on a Honda Civic.

Enter nanomedicine. As described in this issue's Special Report, nanomedicine is the application of techniques from materials science to the world of biomedicine. It could provide just the molecular toolkit the doctor ordered. One tool in the box would be "quantum dots," described in Senior Editor David Rotman's story as molecule-sized aggregates of semiconductor atoms that attach themselves to specific biological structures and light up with a message: "I'm stuck right here on this cancer protein," for instance. Like a flare dropped from an airplane, this signal would trigger a volley of artillery fire in the form of chemotherapeutic agents.



One of the interesting things about the development of quantum dots is that researchers who worked on them originally had no inkling of medical applications. In the 1980s, quantum dots didn't seem to have any applications at all. They were curiosities, remarkable to materials scientists largely because semiconductors usually exist as crystalline solids, not molecule-sized aggregates.

The "aha" moment that turned lab curios into hot technology was the realization that they are on just the right scale to interact with living cells. Paul Alivisatos, a Berkeley chemist, says the light bulb went on for him when he saw that "quantum dots are macromolecules, the size of proteins. Once you realize that the size scales are compatible, you say, 'Okay these things can go together.'" It wasn't long before quantum dots were being looked at as tools for diagnosis and other clinical chores. As freelancer David Voss describes in our Special Report, they're being joined in the nano-toolkit by other compounds and devices that can operate inside the cell.

One sign that nanomedicine is hot is that, as Voss notes, a number of major research universities have established centers to study it. We predict that within five years it will be commercially significant and within 10 it will begin to have a major impact on medicine. That's a bold prediction, and it may turn out to be wrong, but one thing that will not turn out to be wrong is the importance for today's technology of the process of convergence. What's most striking about the story of nanomedicine is that research that began way over *there,* in physics labs, is suddenly all the way over *here*—in biomedicine. The convergence of nanotechnology and medicine is just one example of the exciting research taking place where established disciplines touch. Part of the mission of *Technology Review* is to cover those "boundary effects." Whether it's nanotech and medicine or computer science infiltrating the Human Genome Project, we will be there. And, as long as you read us, so will you.

—John Benditt

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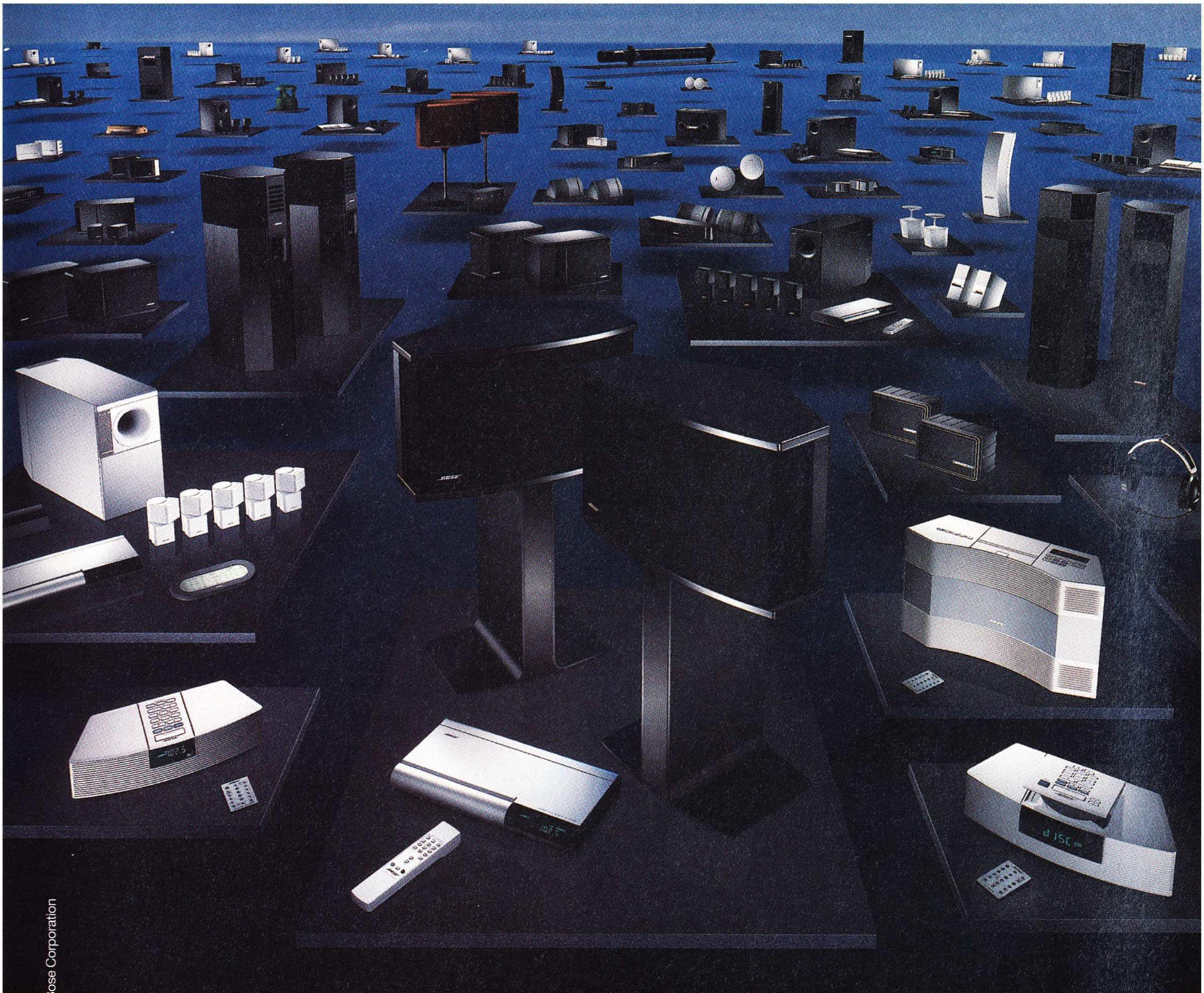

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VOICES *Contributors to Our Pages*

These days, electronic retailing is all about keeping in touch. That's what **Deborah Shapley** found out while reporting our cover story, "Dr. E-mail Will See You Now," in which she profiles a leading company in the field of automated e-mail response. Shapley had fun testing the e-mail smarts of online retailers like Nike and JCPenney by sending them bland product inquiries and angry tirades. Most got back to her right away, she says, while others bungled the chance to get friendly by taking as long as a month to reply. Shapley is a former *TR* editor who specializes in telecommunications; her writing has appeared in *The Christian Science Monitor, The New York Times* and *Time.*


SHAPLEY

E-mail may be the future of online marketing, but **Eamonn Fingleton** thinks that the medium's economic impact is puny compared to what telegraphy achieved in the 19th century. In fact, he believes e-commerce as a whole is dangerously over-hyped. A former *Financial Times* and *Forbes* editor who lives in Japan, Fingleton offers contrarian praise for an economy based on making real stuff, not e-stuff, in this issue's Viewpoint. For more on why advanced manufacturing is a better bet for the United States than a knowledge economy, pick up Fingleton's *In Praise of Hard Industries,* published in September by Houghton Mifflin.


FINGLETON

Whatever your view of the Internet, you probably don't *really* know how it all got started. "Imagine that it's 1962," says author **M. Mitchell Waldrop**, "and you are in the bowels of Robert McNamara's Pentagon in a long corridor of identical doors. Behind one is a 47-year-old civilian. He's got a waistline and a psychology degree, and he's using the military's money to work a revolution in individual empowerment and human creativity." The man is J.C.R. Licklider. His project: modern computing. This issue, Waldrop tells "Lick's" little-known story using material he dug up while researching *The Technology of Enchantment,* a history of computing he's writing for Little, Brown & Co. Waldrop is a physicist turned journalist who lives in Washington, D.C.


WALDROP

When *TR* Senior Editor **David Rotman** first teamed up with *Science* contributing editor **David Voss** in our March/April 1999 issue, it was to deflate the hype that surrounds nanotechnology and to spell out its real potential. Having cleaned nanotech's house of hokum, the Rotman/Voss duo reconvenes in this issue to explore some of nanotech's most promising, and unexpected, applications—in medicine. To see how scientists are using nanoparticles to shed light on disease and constructing nanodevices to fix diabetes, turn to the Special Report on "nanomedicine."

The Special Report features the photography of **Anne Hamersky,** a San Francisco lenswoman whose portraiture is all about *mise en scène*—the artful arrangement of actors and objects. For instance, in her photo of two University of Michigan scientists on p. 61, Hamersky packed the shot with information about her subjects' surroundings (Midwest blustery!), their science (doesn't that tree look just like a dendrimer?) and their humanity (note the whimsical umbrellas). But Hamersky says the props and backdrops "wouldn't matter if their expressions weren't what they are. You can see their determination to discover something." Hamersky also shoots for *New Scientist* and *Time.*


HAMERSKY

Special thanks goes to **April Paffrath** for ably managing the hectic process of getting this issue to press. TR

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"Buderi confirms that using quantitative indicators to compare innovation in companies and countries is here to stay."

Make a Zillion

THE TR100 WAS AN INNOVATIVE WAY TO ring out the first century of *Technology Review* (TR100 Special Section, *TR* November/December 1999). I was a little surprised by things I did not see on the list, like aerospace technology or Microsoft. Just as interesting was the information implicit in the details.

The hardware group, for example, had only 13 members, compared to 22 for software and 23 for the Web (which is mostly more software). Truly, software has stolen the glamour away from hardware.

Were I just starting out and found this issue of *Technology Review* it would certainly affect my thinking on which field to pursue. For innovative research on profound matters that could shape the future, biotechnology is the clear choice. If I wanted to build a better mouse trap and make a zillion bucks, the one word I'd need to know is not "plastics," but "software."

GARY FOSTEL
Portage, MI

I'M GLAD THAT ALL THESE BRIGHT, YOUNG (and wealthy) innovators are around to help us into the next millennium. To my great disappointment, though, all of them seem to be focused in areas that are market-driven and none of them expressed any awareness regarding the declining condition of our planet. I would like to see you publish articles that address issues of food production, preservation technology and responsible manufacturing.

BRUCE H. GLANVILLE
Cinetel Studios
Knoxville, TN

THE ONLY ENTRY IN YOUR TR100 I HAVE A problem with is Magdalena Mik of Walker Digital. This firm files trivial patents, seemingly with one intention—suing future innovators for royalties on obvious ideas and implementations. I suspect that within twelve issues you will be chastising firms like Walker Digital for killing Web innovation with silly patents. At least they'll have your award as a booby prize.

BRAD CLAWSIE
Menlo Park, CA

Indexing Innovation

ROBERT BUDERI CONFIRMS that the use of quantitative indicators to compare the innovative potential of companies and countries is here to stay ("In Search of Innovation," *TR* November/December 1999). The development of such indicators over the past four decades suggests three conclusions:

First, there is no perfect measure of innovation. R&D and patent statistics give a consistent picture when comparing manufacturing companies. But they are less reliable in measuring the increasingly important innovative activities in services and, more generally, in software.

Second, when comparing between companies and countries, time series in R&D and patenting are better than snapshots. The present U.S. position must be interpreted in a longer-term context.

The third conclusion is that, however imperfect, indicators of scientific and technological performance can help us understand the nature and the sources of the innovative activities that are at the heart of corporate and national competitiveness. One striking recent example is the study by Francis Narin and his colleagues at CHI Research in Haddon Heights, N.J., showing that the papers cited in U.S. patents are in general written at major U.S. universities. Given the influence of perceptions of the U.S. model on other parts of the world, science and technology performance indicators could usefully be deployed to assess the degree to which U.S. entrepreneurial accomplishments in information technology and biotechnology are the direct consequences of large-scale federal funding in the underlying academic disciplines.

KEITH PAVITT
RM Phillips Professor of Science Policy
University of Sussex
England

BOB BUDERI'S THOUGHTFUL PIECE ON measuring innovative capacity could have gone a step further by focusing more attention on the key drivers of innovation. The assets that make innovation click aren't just company-based. They include talent, R&D infrastructure, competitive markets, access to capital and close collaboration involving industry, universities and government. These assets, in turn, aren't distributed equally between or within countries. The winners in the global race to innovate will be those economies that create the environment and make the investments needed to turn ideas into high-value products and services.

JOHN YOCHELSON
President
Council on Competitiveness
Washington, DC

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Please include your address, telephone number and e-mail address.
Letters may be edited for clarity and length.

Next-Century Interfaces

TEN INTERFACES OF THE CENTURY? YOU ain't seen nothing yet.

TR's list ("Interfaces: The Century's Top 10," *TR* November/December 1999) is of small interface tools that help enable a rich system of services and functions. But, my, those interfaces seem so trivial. Not the list I would have chosen. After all, it is the services and functions that really count, not the interface.

The power of the interfaces of the 21st century will come from developing technologies that can interact with the rich sensorimotor systems of humans. The ones *TR* selected for this century are rather impoverished in this respect: Each handles one simple parameter, a simple action or experience. What we will get in the future is a

means of capturing the whole experiential capability of people—a dynamic 360-degree surround of sight, sound, vibration, smell, texture, movement and tactile experiences. A means for engaging the entire body.

I look forward to the day when the interface is so embedded in the system it won't be possible to single it out. These are the most exciting interfaces of the twentieth century? Ugh. Just wait until 2099.

DONALD A. NORMAN
President, UNext Learning Systems
Deerfield, IL

First? Who Cares!

AS I READ THE VARIOUS DIATRIBES concerning who did wearable computers first (*TR* November/December 1999), I couldn't help but feel somewhat disappointed by all claimants. The facts are these:

- Wearable-computing development and testing has been ongoing within the research world and Department of Defense for 10 years.
- Wearable computers were deployed on a Naval vessel for test and evaluation in June 1996, and the program is ongoing.
- Steve Mann should move out of the lab and start doing real work.

I think the "who's first" argument should give way to genuine technology development. Fact is, no one knows who was first, and frankly, no one cares.

VINCE QUINTANA
Wearable Computer Systems Engineering
General Dynamics—Bath Iron Works
Bath, ME

Speechless

IN YOUR ARTICLE ON TRENDS IN SOFTWARE (*TR* November/December 1999), AT&T researcher Lawrence Saul says "speech is the most natural and efficient form of human communication." Saul obviously has no acquaintance with the deaf community. His statement alienates a vast global population of active Internet users.

Saul's vocal-elitist comment on what is "natural" and "efficient" disenfranchises major contributors to the cyber community and undermines the very concept of the Internet, the existence and popularity of which relies on inclusivity and democratizing potential. Here, no one's opinion is weighed according to what he or she looks or sounds like. How could anybody be identified as deaf in a newsgroup environment? The "voice is king" attitude carries polarizing, ostracizing collateral.

MIKE GODLEMAN
London, England

On the Mark

BOB METCALFE'S LESSONS FOR INNOVATORS ("Invention is a Flower, Innovation is a Weed," *TR* November/December 1999) were true and entertaining. I was a CPA at a Big 5 accounting firm and now am CEO of the real-estate investment company of a Fortune 500 corporation. Based on 29 years in this complex business environment, I find him on the mark. People need to recognize that they are only as good as the people who work for them.

E.L. HENDRIKSON
Seattle, WA

CORRECTION

Our TR100 profile of Christopher J. Savoie (*TR* November/December 1999, p. 86) scrambled some names and titles. Savoie is chairman and CEO of Dejima Inc.; Babak Hodjat is Dejima's CTO, and Madeline Duva is CFO.

MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW

CONGRATULATIONS

TR100

On November 4, 1999 *Technology Review* brought the TR100—our innovators of the future who were featured in the November/December issue—together on the MIT campus for a gala celebration of our magazine's first century of publication. The energy and creativity of these 100 young innovators was remarkable to see and experience. From this stellar group, *Technology Review* chose one as our first annual Innovator of the Year: Miguel de Icaza of Mexico City, coordinator of the GNOME project, which is creating a desktop for Linux. De Icaza was chosen not only for his individual talents but also as a representative of the open–source software movement, which the editors of *Technology Review* believe will continue to grow in significance in the years to come. *TR* and the sponsors of the TR100 gala celebration congratulate Miguel de Icaza as well as each and every one of the TR100.

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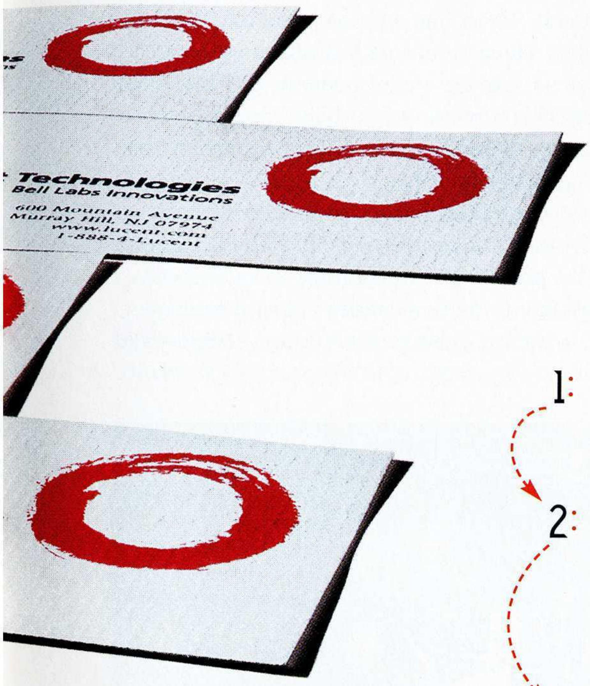

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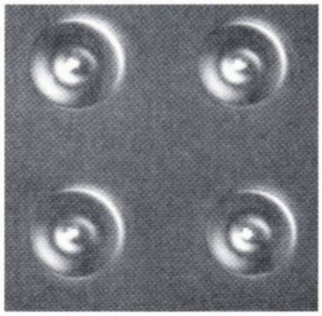
Slick Surgery

After surgery, normally separate surfaces sometimes attach like biological Velcro—a process called adhesion, which interferes with recovery. A Boston startup has come up with the surgeon's equivalent of Saran Wrap to prevent adhesion. According to inventor and CEO Amar Sawhney, Confluent Surgical is testing a device that squirts two streams of polyethylene glycol, a polymer found in everything from eyedrops to lipstick. The streams are chemically modified so that when they meet, they react to form a solid that coats tissues with a jelly-like layer. Confluent has begun human testing in Europe for preventing adhesion in infertility treatments, where scars on the ovaries can prevent implanted eggs from descending into the fallopian tube.



ERIC MAZUR

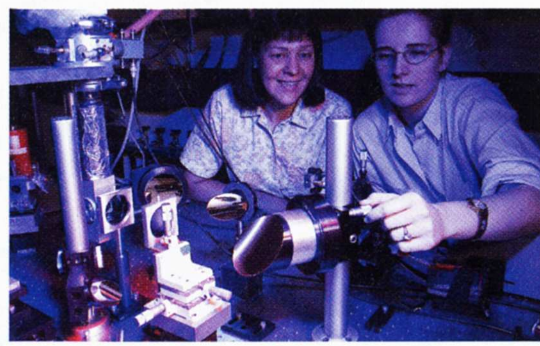
Micrometer-scale holes were excavated in glass by ultrashort laser blasts.

Explosive Data Storage

The need for information storage is exploding. Now some Harvard University researchers are taking that idea literally. They are using an extremely fast laser to trigger tiny explosions that create "microcraters" to encode data. Physics professor Eric Mazur uses red laser pulses lasting a mere 100 femtoseconds to explode glass and other translucent materials. One femtosecond is a billionth of a millionth of a second; there are as many femtoseconds in a second as there are minutes in the age of the universe.

Mazur's graduate student Chris Schaffer took the concept a step further, building a laser that can fire every 40 billionths of a second to create layer after layer of microcraters, much like the pits that provide storage on a CD-ROM—but with the third dimension yielding a 100-fold boost in information density. Harvard has patented this potential application of microexplosions for data storage. Other possible uses: eye surgery and optical computing, where the microblasts could carve tiny spaces required to engineer optical circuits.

Two-Tone Laser



BELL LABS

Gmachl (right) tweaks her double-duty optics.

One key defining property of lasers is that they each produce a single, pure color—or are tunable within a limited range of wavelengths. Now researchers at Lucent's Bell Labs have built the first laser capable of emitting light at two distinct wavelengths.

The two-tone laser was built by Bell Labs researcher Claire Gmachl and her colleagues. At its heart is a semiconducting crystal that does double-duty, emitting one wavelength when a positive voltage is applied and a different one when the voltage is negative. Since the polarity can be switched rapidly, this versatile laser can do the work of two for such applications as pollution detection, which requires one color of light that's absorbed by the target gas and a second color for reference. The prototype device emits mid-infrared light, which is most appropriate for such sensing; future devices could produce different wavelengths for medical and communications uses.

Organics Onscreen

Glance at almost any portable electronic device and you see a liquid crystal display (LCD)—but these ubiquitous screens are far from perfect. Displays using light-emitting organic materials rather than liquid crystals are lighter weight, can be viewed from wider angles and consume less energy. While several crude devices have been commercialized, real competition with LCDs will require that organic electroluminescent (OEL) materials be combined with active-matrix technology, in which the electronics are built into the display.

Eastman Kodak and Sanyo Electric claim to have jointly developed an active-matrix OEL display that will be ready for market in 2001. A dime-thin, 6-centimeter prototype incorporates a thin layer of Kodak's OEL material on a substrate of polysilicon and glass. The companies plan to commercialize the display first for cameras, camcorders and personal digital assistants; future generations could find their way into pagers and cell phones, and eventually into laptop computers.

EASTMAN KODAK/SANYO

Brain Drain

Could a buildup of toxins in cerebrospinal fluid be causing Alzheimer's disease? Stanford University physician Edward Rubenstein hypothesized just that in 1998, noting how in young people, the fluid (which serves as a watery cushion for the brain) is refreshed about four times a day—twice as often as in the elderly.

Doctors at Stanford are now trying to find out whether draining stagnant fluid can slow, or even reverse, the fatal condition. The approach: a 1-meter tube that drains fluid from the brain into the abdomen. CS Fluids, a Redwood City, Calif., startup, has raised $4 million to develop the device, called COGNIShunt. In the nine elderly patients who've received the treatment so far, doctors have seen big drops in the levels of proteins known to damage brain cells.

Dark Vision

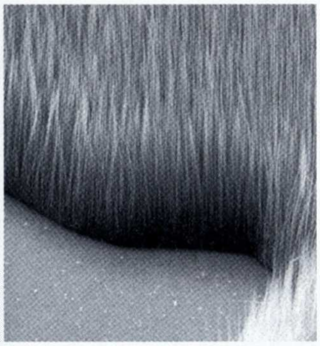
Digital cameras rely on silicon to turn light into electrical current. But for folks who want to work outside the visible spectrum, digital cameras haven't served so well. North Carolina State University physics professor Jan Schetzina, with Honeywell researchers, has replaced the silicon with the semiconductor gallium nitride to build a camera that is sensitive to ultraviolet but not to visible light. Because flames glow brightly in the UV, the military could use such a camera to track missile launches. Industry could apply it to monitor welding processes. The Defense Advanced Research Projects Agency, which helped fund Schetzina's research, has given $1.4 million to Nitres in Westlake Village, Calif., to develop a UV camera.

Krazy Keys

ERGONOMIC-INTERFACE KEYBOARD SYSTEMS

Take a standard computer keyboard, chop it in half, and stand each half on end. Now, put one hand on each side, palms facing in—and type. It might feel strange, but if you're a heavy user, this odd setup could help avert chronic injury such as carpal tunnel syndrome. The "vertical keyboard" lessens strain because it allows the forearm to remain in its neutral position (think handshake). The palms-down posture required by conventional keyboards, in contrast, forces the radius and ulna to cross, a stressed configuration. A recent study by Alan Hedge, director of Cornell University's Department of Design and Environmental Analysis, showed that when typists used the vertical model, they spent significantly less time with their wrists and arms in the strained positions known to increase the risk of carpal tunnel syndrome. Ergonomic-Interface Keyboard Systems—the La Jolla, Calif., company that designed and patented the novel data-entry tool—is seeking licensees to turn the prototype into a commercial product.

Nanofresh Water



ZHIFENG REN

Could forests of nanotubes remove salt from seawater?

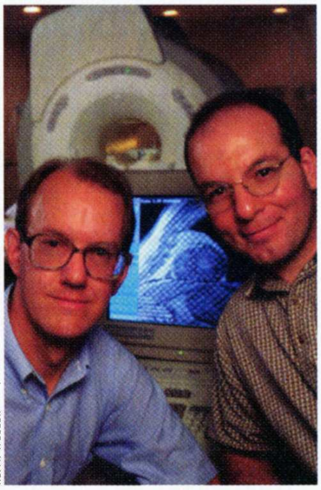
Tiny tubes might help solve one of the world's largest problems—an ample supply of fresh water. A physicist at Boston College is teaming up with an independent inventor to use carbon pipes only a few nanometers (billionths of a meter) across as a fast and energy-efficient means of water desalination. Key to the work is BC professor Zhifeng Ren's discovery of a way to fabricate the tubes as an extremely well-aligned nano "forest."

The nanotubes are electrically charged, and when saltwater runs through them, sodium and chloride ions are electrostatically adsorbed onto the tube surfaces; rapidly removing the charge releases the ions into a waste stream. Because of the nanotubes' high electrical conductivity and large surface areas relative to their volume, they are far more efficient in ridding the water of salt than, say, ordinary carbon. The research is funded by the Defense Advanced Research Projects Agency, which wants to develop a portable, energy-efficient desalination unit. Ren and Mark Andelman, president of Worcester, Mass.-based Biosources, expect to build a prototype this winter.

HARPing on the Heart

Doctors have several indirect ways to assess the heart's health, from the stethoscope to ultrasound and magnetic resonance imaging. MRI can depict blood flow and wall thickening, but doesn't show the internal workings of the muscle—the straining of fibers as they lengthen and shorten with each beat. Now a team at Johns Hopkins University has applied for patents on a new way to process MRI data that gives doctors a view of the heart in action, uncovering otherwise invisible problems.

The system—developed by electrical engineers Jerry L. Prince and Nael Osman—is called HARP MRI, for harmonic phase magnetic resonance imaging. HARP combines a standard MRI scanner with new data-processing techniques to allow precise measurements of muscle strain within minutes. Preliminary tests on the left ventricle look promising, says Prince, who wants to extend the technique's diagnostic powers to other parts of the heart.



KEITH WELLER

Prince (left) and Osman capture the straining heart in action.

Fiber in Your Tank

Clean-burning natural gas is an attractive alternative fuel. Unfortunately, methane (the main constituent of natural gas) is not as potent as gasoline; a practical natural-gas car therefore requires a tank that is either prohibitively large or that stores the gas at high pressure (a dangerous option). Researchers at Oak Ridge National Laboratory have patented a material that may solve this problem.

The material consists of carbon fibers a few micrometers in diameter and a few micrometers long, bonded into a block. Gas infiltrates the porous material and adsorbs to the surface of each fiber. A tank containing this material can hold six times as much methane as a conventional tank holds at the same pressure, says Rod Judkins, fossil energy program manager. Oak Ridge is seeking licensees.

Amount	Company	Offering	Date
$2,160,000,000	Agilent Technologies, Innovating the HP Way	Initial Public Offering	November 1999
$224,200,000	CyberSource	Common Stock	November 1999
$70,400,000	ebookers.com	Initial Public Offering	November 1999
$176,800,000	Finisar	Initial Public Offering	November 1999
$334,300,000	terra	Initial Public Offering	November 1999
$134,600,000	InterTrust	Initial Public Offering	October 1999
$204,000,000	StarMedia	Common Stock	October 1999
$284,100,000	Sycamore Networks	Initial Public Offering	October 1999
$143,800,000	Foundry Networks	Initial Public Offering	September 1999
$750,000,000	Level(3) Communications	Convertible	September 1999
$2,134,300,000	ST	Initial Public Offering	September 1999
$75,600,000	IPIX	Initial Public Offering	August 1999
$41,400,000	Audible	Initial Public Offering	July 1999
$144,900,000	Convergent Communications	Initial Public Offering	July 1999
$52,325,000	Hoovers Online	Initial Public Offering	July 1999
$1,144,202,000	Concord	Common Stock	June 1999
$50,650,000	CyberSource	Initial Public Offering	June 1999
$194,350,000	HSA High Speed Access	Initial Public Offering	June 1999
€215,000,000	Infogrames Entertainment	Senior Unsecured Guaranteed Convertible Notes	June 1999
$103,500,000	NetworkAccessSolutions	Initial Public Offering	June 1999
$43,400,000	Online Resources	Initial Public Offering	June 1999
$52,386,000	EarthWeb	Common Stock	May 1999
$120,750,000	StarMedia	Initial Public Offering	May 1999
$161,000,000	24/7 Media	Common Stock	April 1999
$106,260,000	iTurf	Initial Public Offering	April 1999
$1,552,500,000	Level(3) Communications	Common Stock	March 1999
$345,000,000	LSI Logic	Convertible	March 1999
$57,040,000	RoweCom	Initial Public Offering	March 1999
$64,400,000	Valley Media, Inc.	Initial Public Offering	March 1999
$778,600,000	Network Solutions	Class A Common Stock	February 1999

capital raising • swaps & derivatives • sales & trading • private banking • asset management

The Enlightenment Bug

While the world is eagerly anticipating the Y2K apocalypse, a far more serious "bug," created 300 years ago, gets very little attention—a situation we need to recognize and rectify.

I am talking about the Enlightenment, when people decided to split reason from faith and from the literature of the ancients. This dissociation freed science and technology from the shackles of religion and fueled the Industrial Revolution. The success of industrialization confirmed the wisdom of this division and reinforced the three-way separation among "techies" (who put their faith in technology), the "humies" (humanists) and the religious believers. But with success came problems. Techies began questioning their purpose. Humies became disaffected with gadgets and materialism dominating ideas. Youth, sensing something was missing, turned to drugs. And people focused increasingly on themselves, celebrating possessions and lamenting depressions. Governments separated faith from reason in the school curricula. A politically correct population became increasingly reluctant to say "God." And universities isolated techies from humies in neat cubbyholes. By now, the split has become so ingrained that we're not even aware of it.

Might it heal by itself? The last millennium was dominated by faith. In the new millennium, this dominance is shifting toward technology—people stand awestruck by the miracles of information technology, biotechnology and materials science, which promise to transform our behavior, our being and our surround. But since technology thrives on knowledge and reason, the new era, left unchecked, will aggravate the split, not heal it. Today, the split serves no purpose and we must make an effort to heal it ourselves. Here are the reasons:

Until recently, an educated person was someone who understood the best of what has been written and said. If you needed technology, you bought it, like potatoes, to serve your loftier humanistic goals. Technologists became known as practitioners of "the servile Arts." This view made sense when technology was a small part of our lives, but it is no longer valid. Today, higher purpose may even *originate* with technology, as in the techie idea of a Web site through which people, worldwide, would post their needs or offers of human help, looking for the right match, free of charge. In the future, technology will be as important a driver of noble new endeavors as humanistic ideals were in the past. Staying split will keep us from discovering this new terrain.

Tomorrow, we'll be unable to cope with the world around us if we insist on wearing single-color glasses that let us see only things technological, or humanistic or spiritual. For the world is not neatly partitioned into these bins. Every decision we make, from choosing a school to running a country, will increasingly involve issues that are intertwined across these artificial divisions. We need to heal the split, to find our way through the maze of an increasingly complex world.

If we remain fragmented, we'll be unable to fulfill potential, because we will be running on only some of our cylinders. Human beings have lived for thousands of years without this split. And we were not always as impressed with reason as we have been in the last few centuries. It is ironic, yet inescapable, that so many thinkers were seduced by reason. We can't help but be impressed by this unique capability of our brain, which in its exquisite architecture and processes holds our awesome power to think. But what does reason have to do with the love of a child, the beauty of flower, or the eternity of stone? At this, the beginning of the third millennium, the Enlightenment bug has caused us to overrate reason at the expense of faith, and technological reason at the expense of humanistic ideas.

Agenda for the new millennium: Heal the division of humanity into "techies," "humies" and religious believers.

Another reason for repairing this bug is people's inherent need for spirituality, which, psychologists tell us, offsets the powerlessness we feel before the mysteries that surround us. In an increasingly rational world, how might our children fulfill human need that has led billions to religion throughout the centuries? Never mind grandstanding on the easy answer that the state shouldn't glorify any particular sect in the schools. Good. Let's not take sides. Now what? Will learning in this millennium stay chained to reason? What of birth, friendship, love, marriage, illness, divorce, conflict, death, origin, purpose?

We don't know enough to answer these questions. But we should know enough not to be so smug in a one-sided adulation of reason, technology, humanism or spirituality. Let's take a cue from the long history of our species and begin integrating our divided selves toward becoming, once again, whole. This does not mean we should all strive to become spiritual technologist-humanist dilettantes. Our differences will persist and continue to delight us. Rather, we should reach within, and awaken, listen to, and nurture the pieces of our split-apart selves, encouraging especially the ones we can barely hear. And we should begin doing so with our children at home, with teachings and curricula in our schools and universities, and with our daily activities in our professional and personal lives.

This unification is not easy. But it is worthy of our millennial resolution. Let's fix the Enlightenment bug and, once again, stand in awe before the sunset, the wheel and that which may lie behind them. ◊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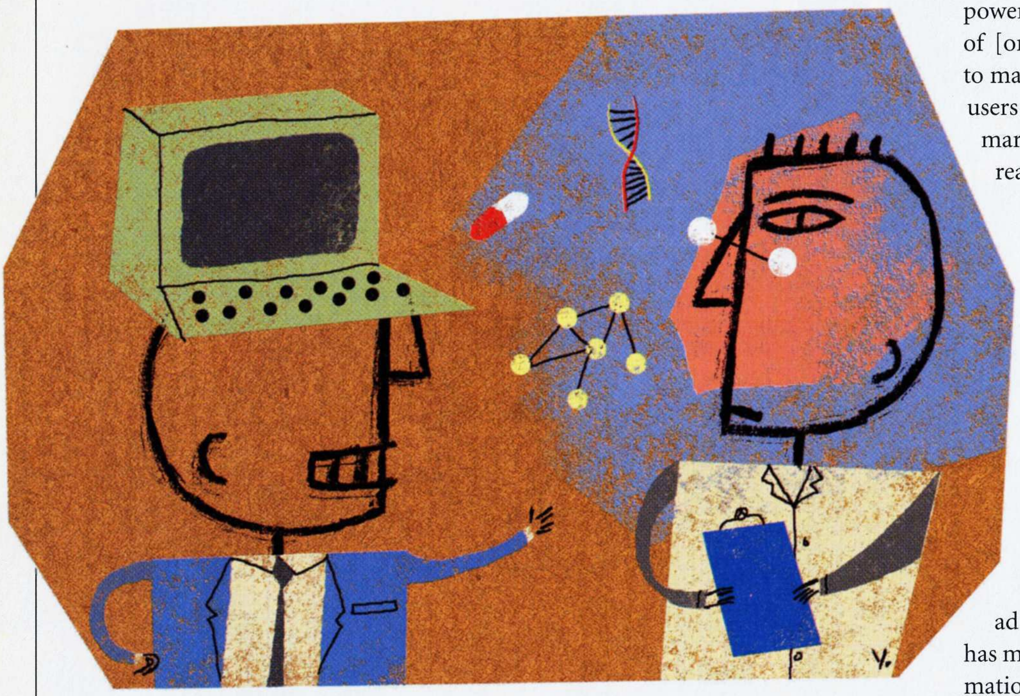


BIOTECH

G-Commerce

The latest commercial Web offering: genetic data

CONCERNED ABOUT BEING LEFT OUT of the race to patent the human genetic code? No problem. Just fire up your Web browser, take out your Visa card and head over to www.GeneSolutions.com. The Web site sells gene information for as little as 10 cents per base (the chemical unit of DNA).

Launched in September by Hyseq, a Sunnyvale, Calif., biotech firm, GeneSolutions represents the marriage of two hot technology trends—e-commerce and genome research. According to Hyseq CEO Lewis Gruber, his company had accumulated a vast warehouse of gene data but wanted to focus its efforts on developing a few promising drugs. Gruber says Hyseq decided to throw open its doors and let researchers "purchase the genes on a point-and-click basis."

The move is part of a familiar sounding e-commerce chain of events. Although Hyseq still hadn't sold a dime's worth of DNA-sequence information through the portal as *TR* went to press, plenty of other companies are also scrambling to stake a claim in gene commerce. Recent entries include Australia's eBioinformatics and Pangea Systems of Oakland, Calif., which was scheduled to launch a portal called DoubleTwist.com last month.

Pangea's main business is selling the "bioinformatics" hardware and software that pharmaceutical firms use to mine public and private gene databases for the clues they need to create new drugs. But these costly and sophisticated tools are outside the reach of most scientists, says John Couch, Pangea's CEO—and so the company decided to broaden its market by taking its business online. With DoubleTwist's easy-to-use interface, biologists can enter a gene's DNA code and get back a state-of-the-art analysis. "You need some real specific expertise to get these answers right now," says Couch. "The notion of our site is to get the power of bioinformatics into the hands of [ordinary] researchers." Pangea looks to make money by charging fees to heavy users and corporations, as well as by marketing products such as chemical reagents online.

DoubleTwist's software relies on gene data residing on public domain servers, such as those maintained by the National Institutes of Health. But biotech companies also plan to start giving away bits and pieces of proprietary data on the portals. Posting a teaser on the Internet is "an effective way to get a sample of what you do into the hands of many thousands of researchers," says Peter Meldrum, CEO of Myriad Genetics in Salt Lake City. Myriad has made a free database of protein information *(see "The Next Genome Project," TR May/June 1998)* available both on its own Web site and through Pangea's DoubleTwist.com.

In the future, the gene-commerce sites could become trading posts for patents as well as data. In fact, that's just the expanded business that Hyseq's GeneSolutions is hoping to get into. As Gruber explains it, every drug company and university is amassing patents on genes, most of which they don't use but which may be preventing others from investing in research that could lead to life-saving medicines. Gruber figures one way to rationalize the marketplace is to let scientists browse for genes and trade intellectual property online. "E-commerce lets information exchange hands and industry develop in a way that's impossible if information and patent rights are balkanized," says Gruber.

Some biologists are skeptical of the commercial portals, while others worry that health-conscious consumers who are already doing their own health research online might start dialing up information on their DNA. Yale University bioinformaticist Mark Gerstein says: "If you want to connect the public to their genetic information, that's better done through a doctor than a Web site."

—Antonio Regalado

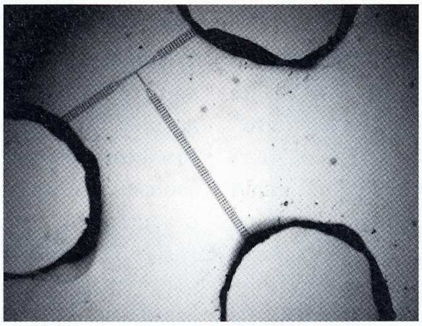
INSTRUMENTATION

Sorting Out Life

Rubber chip promises a cheap way to segregate cells

TO UNDERSTAND DISEASE AND develop new drugs, researchers often must begin by sorting the jumble of cell types in a living organism—tumor cells from normal cells, for instance. In some cases, a refrigerator-sized "fluorescence-activated cell sorter," or FACS, can do the job. These machines, however, are expensive ($250,000), tricky to operate and prone to contamination. Now a team at Caltech, led by applied physicist Stephen Quake, has built a "microFACS," reducing the complicated system of pumps, tubes and nozzles to micrometers-wide channels in a stamp-sized rubber chip.

George Whitesides, a Harvard University chemist who developed some of the technology used by the Caltech team says, "Quake brings the perspective of a physicist to this problem in bioanalysis, with results that are, to me, spectacular." Bay Area-based Mycometrix aims to make prototype microFACS systems available to potential customers by year's end; the startup was formed in 1999 to commercialize technologies from Quake's lab. Vice president of business development Todd Krueger estimates that the reader will sell for $40,000, the disposable chips for less than $20 apiece. By making cell sorting cheaper and simpler, he says, the system should open up a host of new applications for the technique outside the lab, including doctor's-office diagnosis and food or water screening.



ANNE FU, CALTECH

Electricity drives cells from the bottom well to the T-junction where they go either left or right.

The microFACS uses laser light and electricity to sort a cell mixture. Three 2-millimeter-wide wells on the chip are connected by a T-shaped network of channels. A researcher first tags the cells with fluorescent markers, then loads them into the bottom well and drives them toward the channel junction with an electric current. The channels narrow to just a few micrometers near the junction, forcing the cells to proceed in single file. A laser aimed at the junction hits the different markers and causes each cell type to fluoresce in a particular color—say, red for tumor and blue for normal. A detector prompts a computer to adjust the current to drive each cell to the left or the right, into a waste well or a collection well.

One reason the microFACS is so cheap is that the chips are made by soft lithography, an experimental process developed by Whitesides. It's potentially far less expensive than micromachining; instead of carving individual chips, researchers cast them in a reusable silicon mold.

Whitesides calls Quake's cell sorter "an elegant piece of design," and points out that it could be coupled to other ultrasmall analytical systems, such as single-cell DNA sequencers. Indeed, one of Quake's future aims is to build the sorter and all the other scaled-down devices needed for a particular experiment linked together on one chip, a goal that many others in the field are hotly pursuing. **—Rebecca Zacks**

CHAPTER TWO

Satellites, Silicon, a Startup

Journalists are often slammed for forgetting stories after the initial news cools. There's some truth in that charge, so we've decided to revisit selected stories. Call it "Chapter Two" in the life of news. We'll bring these offerings to you from time to time in Benchmarks.

- Our March/April cover story reported the impending commercial availability of spy-quality satellite images of the earth. Surviving a failed satellite launch in April, Thornton, Colo.-based **Space Imaging** became the first to offer images with 1-meter resolution, capturing views of Washington, D.C., in late September.
- European Global Positioning System users have long been aware that, since GPS is a U.S. military monopoly, the signal they rely on could be jammed at American discretion. The European Space Agency has approved the first appropriation—$42 million—toward a European equivalent of GPS called **Galileo**. The new system could further complicate things for American GPS firms, whose struggles were described in the July/August issue.
- An **Intel** researcher has warned that the industry's long-standing ability to shrink silicon devices, increasing their speed and power, is set to fail in the next few years. In the journal *Science*, Paul Packan wrote that rapidly approaching limits of scale are "the most difficult challenge the semiconductor industry has ever faced," echoing concerns voiced by Hewlett-Packard's Stan Williams in *TR*'s September/October issue.
- GNOME ground zero is moving from Mexico City to the Boston area. The project coordinator for Linux's graphical user interface, **Miguel de Icaza**, (whose work we described a year ago) has been funded by the Linux Fund to start a company to develop open-source applications. De Icaza checked out office space in November, when he was honored at MIT as a member of the TR100 and *TR*'s Innovator of the Year for 1999. **—RZ**

HYPERTEXT

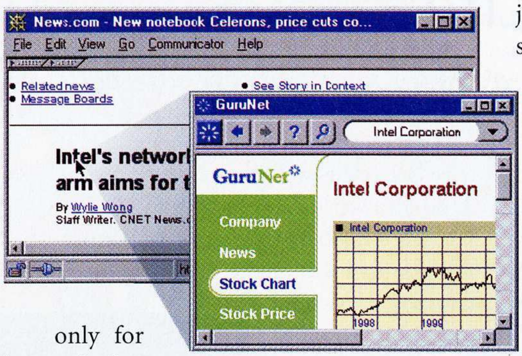
Every Word a Link

New software extends hyperlinking

IN THE WEB-IFIED 1990S, WE'VE gotten used to hyperlinking—the ability to click on a highlighted word to call up other information. But in most of the text that fills your screen—word processing files, e-mail messages and such—there's not a hyperlink in sight. Two new tools aim to let you click on *any* word in any document and get additional information.

Software introduced last fall by Palo Alto, Calif.-based GuruNet.com makes every piece of text on your screen "alive." As long as you're logged on to the Internet, you can click on a word and within three seconds a window pops up offering a dictionary definition, brief encyclopedia entry and a list of Web links on the topic. "We think that people should be able to point at a word and say, 'tell me more,' and within three seconds get an answer," explains GuruNet founder and president Robert Rosenschein.

GuruNet, which stores the databases on its servers, is currently available



only for Windows computers (free download at www.gurunet.com), but Rosenschein says a Macintosh version should be available soon; the company may also adapt the product for Linux and Palm computers. Future refinements may enable users to select their own reference databases instead of using the ones GuruNet has chosen.

While GuruNet is for the basically curious, Babylon.com aims to satisfy the rapidly growing subset of Net users who know little English. Like GuruNet, Babylon.com, an Israel-based subsidiary of Mashov Computers, turns every word on the screen into a hyperlink. But Babylon's primary function is translation to and from English. The premise is that anyone using the Internet is likely to know roughly 1000 basic English words; Babylon's job is to translate the other 3 million or so words.

The translation database is downloaded during installation into the user's computer, and so, unlike GuruNet, the software works even when you're not online. Someone might, for example, use Babylon to decipher a downloaded Web page or a piece of English-language e-mail. Translations are provided between English and eight other languages: Spanish, German, Japanese, French, Dutch, Italian, Portuguese and Hebrew. The free Babylon software already has about 2 million registered users around the world, says CEO Shuki Preminger.

GuruNet and Babylon both extend the power of hyperlinking to documents that were not structured that way to begin with. Given that only a tiny portion of the world's literature has been coded to include Web-style linking, that's a far-reaching concept—and it could change forever the expectations people have of words on their screens. —**Herb Brody**

INTELLECTUAL PROPERTY

Gifts that Keep Giving: Patents

This Christmas, universities added patents to their wish list. In the latest trend in corporate philanthropy, large companies are giving away millions in unused intellectual property, and walking away with a tax write-off—and plenty of good will.

In October, Procter & Gamble gave 40 U.S. and international patents to the Milwaukee School of Engineering; all the gift-wrapped items are related to a technique to speed up product design. The gift is part of "a comprehensive re-thinking of the way we use our patent rights," says Jacobus Rasswer, P&G vice president and general counsel for patents. Other corporate giants, including DuPont, Dow Chemical and Hoechst, have been in a similarly generous mood (see table).

This largesse might only be the beginning. Procter & Gamble, for one, holds some 25,000 patents worldwide—but only 10 percent cover technology the company actually uses. In the past the multinational corporation just "stored the rest away," says Rasswer. "That mindset has totally changed," he says, since P&G set about trying to get more value out of its intellectual property holdings two years ago. In addition to donating patents, P&G has begun licensing patents to other companies and posting inventions for sale on an online patent exchange called Yet2.com that it helped launch.

To see a return, however, universities have to invest—in marketing the technologies and in research. "You are acquiring a fishing license. A patent is just a piece of paper unless you can add value to it," says Ron Sampson, president of the Mid-American Commercialization Corporation, a group that works with Kansas State University. Sampson has already turned away one would-be donor. "We just couldn't see the benefit," he says. —**AR**

GIVER	RECIPIENT	VALUE
Eaton	Mid-American Commercialization	$17 million
Ford	National Center for Manufacturing Sciences	$22 million
Dow Chemical	Rensselaer Polytechnic Institute	$4 million
DuPont	University of Iowa	$35 million
Hoechst	Clemson University	$12 million

Source: Alan Fisch, Howrey & Simon, Washington, D.C.

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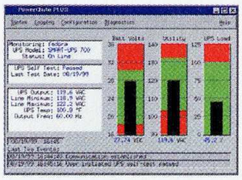

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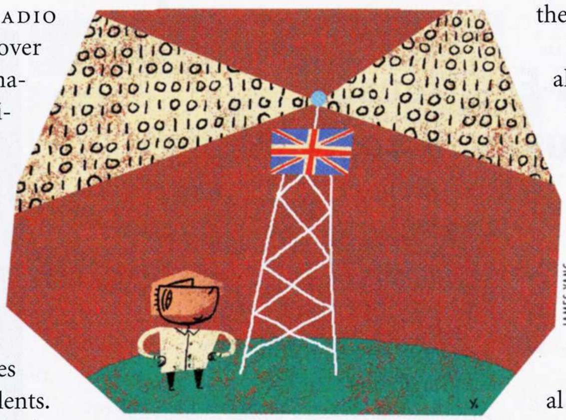
COMMUNICATIONS

Digital Wireless

British radio goes digital, led by the BBC

THE TECHNOLOGY BEHIND RADIO broadcasts has changed little over the years. Stations still broadcast analog-based FM and AM signals. Digital radio, however, could be the wave of the future, catapulting the medium into the communication revolution. Transmitting a digital rather than an analog signal offers clear sound, interference-free reception and space for dozens of stations in the bandwidth that carries a mere two or three analog equivalents. The technology is so promising that in the United States several groups are scheduled to make digital radio widely available in a year or so. But British broadcasters have beaten the Yanks—and the rest of the world—to the punch.



JAMES YANG

The United Kingdom has staked its claim as the birthplace of digital radio following the launch of the first stations available exclusively via digital broadcast. With digital services elsewhere in the world still at an experimental stage, the British broadcasters—including the venerable BBC—hope they have, literally, set a standard others will quickly follow.

The BBC first started simulcasting its national radio services four years ago, sending both analog and digital signals. Until recently, however, few listeners were able to hear the digital transmission. Manufacturers have been reluctant to develop a new generation of radios before there were digital stations to give consumers a reason to buy. This catch-22 was broken, however, by the commitment of a commercial radio group—GWR, the company behind the U.K.'s popular station Classic FM—to launch a number of digital radio stations including several that are exclusively digital. The cause was aided last summer when the BBC and GWR forged a partnership to promote digital radio. "Digital promises a quantum shift in our perceptions of what radio is," says Quentin Howard, managing director of Digital One, the company set up by GWR to develop its digital radio interests.

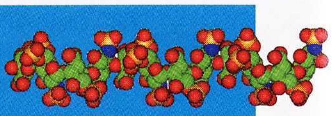
Maybe. But for the time being, Britain's fledgling digital-radio industry will likely not be a money maker. While a number of companies, including British manufacturer Arcam, are already producing a range of digital radio receivers, the number of sets on the market is only a few thousand and sets still cost a pricey £300 ($480). But Howard predicts that cooperation between Digital One, the BBC and other commercial broadcasters will increase demand and, as supplies of digital sets increase, retail prices will fall. "It is up to the broadcasters to kick start the market," he says.

The development of digital radio has also been delayed by the lack of a worldwide broadcasting standard. Europe has settled on a standard called Eureka 147, which has also been adopted by Canada, Mexico, South Africa and Australia. In fact, the only country looking for an alternative is the United States. To confuse matters further, European digital radio is broadcast via terrestrial transmitters, whereas the Americans are planning to broadcast via satellite. The U.K. broadcasters, however, feel their decision to encourage more digital sets to be manufactured and to create consumer demand has put Eureka 147 in position to be adopted as a global standard.

Tune in on your digital dial to see if they're right. **—Meg Carter**

BIOMEDICINE

Sugar-coated Medicine



DNA and proteins are the stars of biotech, but they aren't the only prime players in biology. Recent studies show that complex sugars called polysaccharides have a critical role in cell development and tumor formation. Like DNA, these sugars are composed of basic chemical building blocks whose sequence determines their biological functions. Until now, however, sugars have remained a bit player in the biotech revolution—partly because sequencing a single polysaccharide could take months.

A new technique developed by a pair of MIT researchers, Ram Sasisekharan and Ganesh Venkataraman, could change all that, allowing sugar sequences to be deciphered in days. By getting the job done much more efficiently and quickly, the MIT approach paves the way for researchers to clarify the exact roles complex sugars play throughout the body. The potential payoff: future drugs that target sugars linked to viral infections, cancerous tumors and other diseases. "The MIT group has taken this technique to a very high level of utility," says Merton Bernfield, a professor of cell biology at Harvard University.

Lodged between cells, polysaccharides known as glycosaminoglycans (GAGs) regulate cell-to-cell communication. These sugars are highly specialized; the arrangement of their building blocks dictates the message neighboring cells receive, and ultimately serves to differentiate organs. GAG sequences in the liver, for instance, differ substantially from those in the kidney; those in healthy tissues differ from those that are diseased. Biomedical researchers would like to be able to divide the body into unique, sugar-based "zip codes," says Venkataraman. "Once you know these zip codes, you can distinguish between normal and abnormal tissues."

The MIT researchers now aim to design a machine to automate the procedure. "We're at the tip of the iceberg in the polysaccharide field, where DNA and protein research was years ago," says Sasisekharan. **—Mark Dwortzan**

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CriticalPath	$108,000,000	Initial Public Offering
CriticalPath	$172,800,000	Follow-on Offering
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InfoSpace.com	$286,400,000	Follow-on Offering
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Liquid Audio	$63,000,000	Initial Public Offering
looksmart	$92,400,000	Initial Public Offering
MapQuest.com	$69,000,000	Initial Public Offering
Media Metrix	$51,000,000	Initial Public Offering
Media Metrix	$151,500,000	Follow-on Offering
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Net.B@nk	$78,300,000	Follow-on Offering
NetGravity	$128,500,000	Follow-on Offering
NetIQ	$39,000,000	Initial Public Offering
NetObjects	$72,000,000	Initial Public Offering
netopia	$41,800,000	Follow-on Offering
Network Solutions	$778,600,000	Follow-on Offering
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QXL.com	$27,100,000	Initial Public Offering
razorfish	$48,000,000	Initial Public Offering
RealNetworks	$232,000,000	Follow-on Offering
Redback Networks	$57,500,000	Initial Public Offering
StarMedia	$204,000,000	Follow-on Offering
Student Advantage	$48,000,000	Initial Public Offering
TiVo	$88,000,000	Initial Public Offering
USSEARCH.com	$54,000,000	Initial Public Offering
Value America	$126,500,000	Initial Public Offering
VeriSign	$221,400,000	Follow-on Offering
WebTrends Corporation	$82,500,000	Follow-on Offering

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Nano-Hype

IMAGINE A MICROSCOPIC COMPUTER THAT assembles itself, atom by atom, then calculates at a speed faster than today's zippiest electronic chips. Now imagine this same computer is unbelievably cheap—dirt cheap, in fact. Sounds too good to be true? Well, some people think it's real. This is the idea behind nanotechnology: that individual molecules can serve as digital switches and, acting in concert with billions of other molecular switches, replace digital computers.

If this vision can be realized, molecular computers could in one swoop destroy the enormous investment by the semiconductor industry in "fabs," the plants that fabricate chips. The most advanced plants today cost billions of dollars. Not only would molecular computers disrupt what's probably the world's most important manufacturing industry next to cars, they also solve a looming "problem" presented by the laws of nature. Chip makers face physical limits in etching circuits on the wafer-thin material called silicon. One widely accepted estimate says the limits of silicon will be reached by 2014.

If you think a self-assembling molecular computer is right around the corner, you may have succumbed to the Big Lie.

So molecular computers—or talk of them in the nation's most prestigious newspapers and magazines, including this one *(see "Computing After Silicon,"* TR *September/October 1999)*—appear to be coming along just in the nick of time. Like the cavalry in a John Wayne movie, they will rescue high-technology from the specter of stagnation. This is a beautiful story, one that warms the heart of the capitalists who pay for each new round of innovation in computing and other fields. There is only one problem with this story: It's a lie. And not a small lie either. In journalism, the story of molecular computing is a Big Lie.

The fact that it's a lie isn't all that surprising, however. For as long as innovators have been around, they've lied. Lied about the possible obstacles to further innovation. Lied about the utility of their innovations. Lied about the economic advantages of their breakthroughs. Lied about the breakthroughs themselves—all in the service of promoting their innovative technologies.

Remember artificial intelligence? Computers were going to automatically translate from one language to the next. Take dictation. Run factories without human intervention. Lead space missions. And we're not talking about predictions made a couple of years ago. These fanciful ideas were promoted way back in the middle of the last century: in the *1960s.* How about the energy that was going to result from nuclear power: "too cheap to meter," one enthusiast crowed. Or the nuclear-powered airplane. Does that ring any bells?

This impulse to misrepresent is natural. Innovators have it tough. There are no sure things. They must battle for "mind share." Especially when an innovation attacks an existing technology—as most do—it takes a lot of sizzle to get consumers to pay attention. And investors don't like to spend their money on losers. So every new technology must be a winner, which is how little lies grow up to be big ones.

In the claims for molecular computing—claims that have periodically erupted since the 1980s but without hard evidence—the little lies are growing up at a rapid clip.

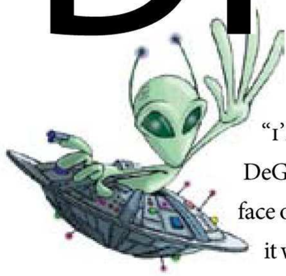
Begin with economics. Though molecular computers have only been crudely demonstrated, leading researchers already are touting their presumed efficiency. The molecular computer will not just be cheap, says Mark Reed, head of electrical engineering at Yale, "it will be dirt cheap." We've heard that before. Or consider the perennial problem of scaling up from a simple molecular device to a real working computer. It's one thing to demonstrate a single molecular switch, which has been done. But no one has yet shown how to tie together gangs of billions of switches with "wires" only a dozen atoms thick.

Still, there's enough potential here to create a buzz. Hewlett-Packard, a top computer maker, is experimenting with both molecular switches and molecular "wires" in its labs. Academic research teams are doing the same. Papers are getting published. The Clinton administration is even talking about launching a national nanotech initiative. And predictably, the Pentagon is already taking a few bows, boasting of the foresight of its Defense Advanced Research Projects Agency, which has financed much of the early work in this field.

Don't get me wrong: The advances in molecular computing deserve attention. But that attention should be balanced by a tough-minded skepticism. And that's not happening. Unfortunately, the suspension of disbelief that lets us believe the tall tales is being fueled by the mania for the "new new thing"(to quote the title of a recent book by Michael Lewis) and the abject fear that some unheralded innovation will change the world as we know it—but that we will have missed seeing it coming. The over-the-top quality of the current nanotech hoopla seeps out in odd ways. One sign that the nano-bubble will burst is the admission by a leading nano-advocate that until this latest news flurry, he and his fellow travelers harbored their own doubts. "Although we believed in some rational way this was the way to go," he told *The New York Times*, "among ourselves we were continually forced to reassure ourselves that we weren't crazy."

Excuse me, but maybe you are crazy. ◊

Dr. E-mail Will See You Now



"I'M GAY!" THIS ANNOUNCEMENT BY TV ACTRESS ELLEN DeGeneres during her prime time "Ellen" show might not, on the face of it, seem a signal event in the history of online commerce. But it was. Ellen's "outing" on the April 30, 1997, ABC broadcast fueled a nationwide controversy that spilled over to the show's corporate sponsors. One, the venerable JCPenney department store chain of Plano, Texas, found its fledgling presence on the World Wide Web inundated with e-mail of a kind and quantity it had never seen before. Anti-gay critics flamed DeGeneres and belted JCPenney for supporting her show. Supporters were just as vehement. Not exactly cardigans and cookware.

For technologists, though, the real news was how JCPenney's e-mail system handled the fuss. At the time, Middle America's favorite apparel retailer was experimenting with a pilot version of EchoMail, a new type of automated e-mail classification and response system from General Interactive, a young Cambridge, Mass., software firm. Not only did EchoMail go on routing and replying to regular queries about orders and returns, but it recognized that the "Ellen" messages didn't fall into a preset category.

It also recognized that some of these people were mad.

BY DEBORAH SHAPLEY

PHOTOGRAPHS BY JOHN SOARES

Is software that replies to customers automatically the key to success in e-commerce? Ask the doctor.

Of course, humans staffing JCPenney's stores and catalog call centers were also getting calls about "Ellen." But the volume of complaints to any one site couldn't compare with the power, and immediacy, of the signal received by JCPenney's e-mail department. The EchoMail program was reporting a sudden spike in the number of angry incomings, and headquarters knew it had a major customer relations problem. Right away the PR department drafted a statement for the company to use in reply to the ornery Ellen-mail.

The "Ellen" brouhaha caused the show to lose JCPenney as a sponsor, as the retailer declined to renew for the next season. EchoMail, however, fared better. As recounted by V.A. Shiva, aka "Dr. E-mail," General Interactive's founder and CEO, and the inventor of EchoMail, the system's early alert over "Ellen"during the testing period helped convince JCPenney to sign up for the service—adding it to the blue chip list of companies, including Nike and Citibank, that have bought Dr. E-mail's prescription.

Relationship medicine: General Interactive CEO V.A. Shiva helps retailers manage customer relationships—electronically.

EchoMail, says Shiva, is a combination of pattern recognition techniques that, by decoding, routing and in many cases answering e-mail, lends his customers the "sensory and cognitive ability" needed to win customers online and keep their loyalty. "Our goal is to become a company's central nervous system," says Shiva, one that uses e-mail to provide clients not only the "capacity for quick response" but also the "look and feel" they want.

Americans sent 335 million e-mails per day in 1999, and spent more than $20 billion online.

Today, traditional retailers are realizing that they need a virtual presence on the Internet as clear and compelling as a Gap storefront. After all, as commerce goes online, so does the business-consumer relationship. And, Shiva argues, "e-mail is the ultimate relationship builder."

Ninety-three million Americans sent a total of 335 million e-mails per day in 1999, according to Jupiter Communications. Personal e-mail has grown 50 percent per year, a surging tsunami of messages that's outstripping even the Web, whose users have grown just 21 percent per year, says Jupiter. And 23 million Americans used e-mail to order goods from corporate Web sites, accounting for much of the $20 billion consumers spent online in 1998. That figure's set to top $140 billion by 2003, according to Forrester Research, while business to business online sales grow from $109 billion to $1.3 trillion.

If the medium for e-commerce is e-mail, small wonder that General Interactive (which, at 4 years old, is already the granddaddy of intelligent e-mail response) is now feeling heat from competitors who share Shiva's belief that the key to the future of online retailing lies in electronic "customer relationship management." Rivals include other startups such as Brightware and Kana Communications, and also titans of the 1-800 call business such as Lucent Technologies. The field of intelligent e-mail response did $75 million in sales in 1998, and is expected to grow to $340 million by 2003 according to International Data Corp.

Although intelligent e-mail response is a small industry, observers believe its innovations could have a far greater impact by helping to determine winners and losers in e-commerce's frenzied grab for market share. The swift emergence of giants such as Amazon.com and eBay has sounded the drumroll for big brick-and-mortar firms now venturing online. "In three years there won't be that many giant consumer retailers online. There will be lots of consolidations and shakeouts," believes Shelley Taylor, president of the consulting firm Shelley Taylor & Associates. And after surveying the 1,000 largest companies' online prospects, Taylor believes those who succeed "will win due to the quality of their communication."

So far, about 25 of the biggest names in corporate America—including Allstate, IBM and Procter & Gamble—have delivered at least part of their online persona to the care of Dr. E-mail.

The Eureka Moment

ON A RECENT SATURDAY MORNING, DR. E-mail could be found bustling around General Interactive's spare offices at the top of steep stairs over Sage's grocery store in Harvard Square, across from the landmark Brattle Theater movie house. Shiva's full-cheeked face makes him look younger than his 36 years. His shoulder-length loose-hanging black hair and tobacco-hued skin give away his birth in Bombay, as Vellayappa Ayyadurai Shiva.

Outgoing, voluble and distracted, Shiva is a tumbleweed of ideas at once entrepreneurial, intellectual and artistic. He is the author of the 1996 book *Arts and the Internet: A Guide to the Revolution,* and holds master's degrees in both visual studies and mechanical engineering from MIT. He's still working to get his PhD in information theory and cybernetics, however. For now, the "Dr." of his self-assumed persona is pure marketing.

Shiva's intial encounter with e-mail came in 1979. A bored high school junior then living in Livingston, N.J., Shiva was asked by a Rutgers professor to help with a computer network linking three hospitals. When he first heard someone say "electronic mail," Shiva recalls, "I thought it meant current flowing through paper."

His networking project became a science fair winner, a semifinalist in the Westinghouse Science Talent Search and earned Shiva a ticket to MIT in 1981. During his work for a degree in computer science, what came to fascinate Shiva most was pattern recognition, a field of mathematics that looks to draw meaningful information from noisy data, and which is closely allied with artificial intelligence research.

For instance, Shiva helped another Rutgers professor scan brain wave data from 600 sleeping babies for patterns that could show which were at greatest risk of Sudden Infant Death Syndrome. At MIT, Shiva analyzed the touch patterns sensed by deaf-blind people who use Tadoma, a language in which the listener spreads her hand lightly across the face of the speaker to recognize words.

After receiving a master's degree from the MIT Media Lab, Shiva was recruited by MIT instructor Frederick Foreman to study patterns in ultrasonic waves sent through materials to map their internal structures. Foreman recalls they spent "12 hours a day" on the project during the late 1980s—but Shiva's thoughts were on the digital world as much as the physical one. "He had this idea he could use the same techniques for information. He kept saying, 'I can manipulate information as if it's a wave.' And he kept talking about how waves of information and e-mails and graphics going all over the place were going to be the next big thing," Foreman recalls.

By then, Shiva's Eureka moment was close at hand. After getting his second master's in 1990, he helped to critique early Web search engines for the National Institute of Standards and Technology. In 1993, he participated in a White House contest for routing e-mail. "I was reading thousands and thousands of e-mail, and realized they are not all that different," Shiva says. In fact, looking below the surface, e-mail tended to be almost robotically repetitious. "So I said: 'Maybe they have fundamental properties which could be recognized, like physical matter.' "

Shiva worked up algorithms to detect what he concluded were an e-mail's essential features. He named the software Xiva, and founded a company called Millennium Cybernetics to commercialize the idea. That

GRAPHICS COURTESY OF GENERAL INTERACTIVE

was in 1994, a time when e-mail was still small potatoes, and no major retailer had made a commitment to the Internet. Even Jeff Bezos was an unknown working from a 25-square-meter office in Seattle; he would not flip the switch to light up Amazon.com until July of the next year.

But when a friend told Shiva that AT&T was spending $10,000 on a Web presence, and needed help with its surprising volume of e-mail, Shiva sought an introduction. No matter how Web commerce unfolded, he figured, big, mainline firms would have to go online and get lots of e-mail. After a pilot demonstration of Xiva—now trademarked EchoMail—AT&T signed in 1996.

Essence of Message

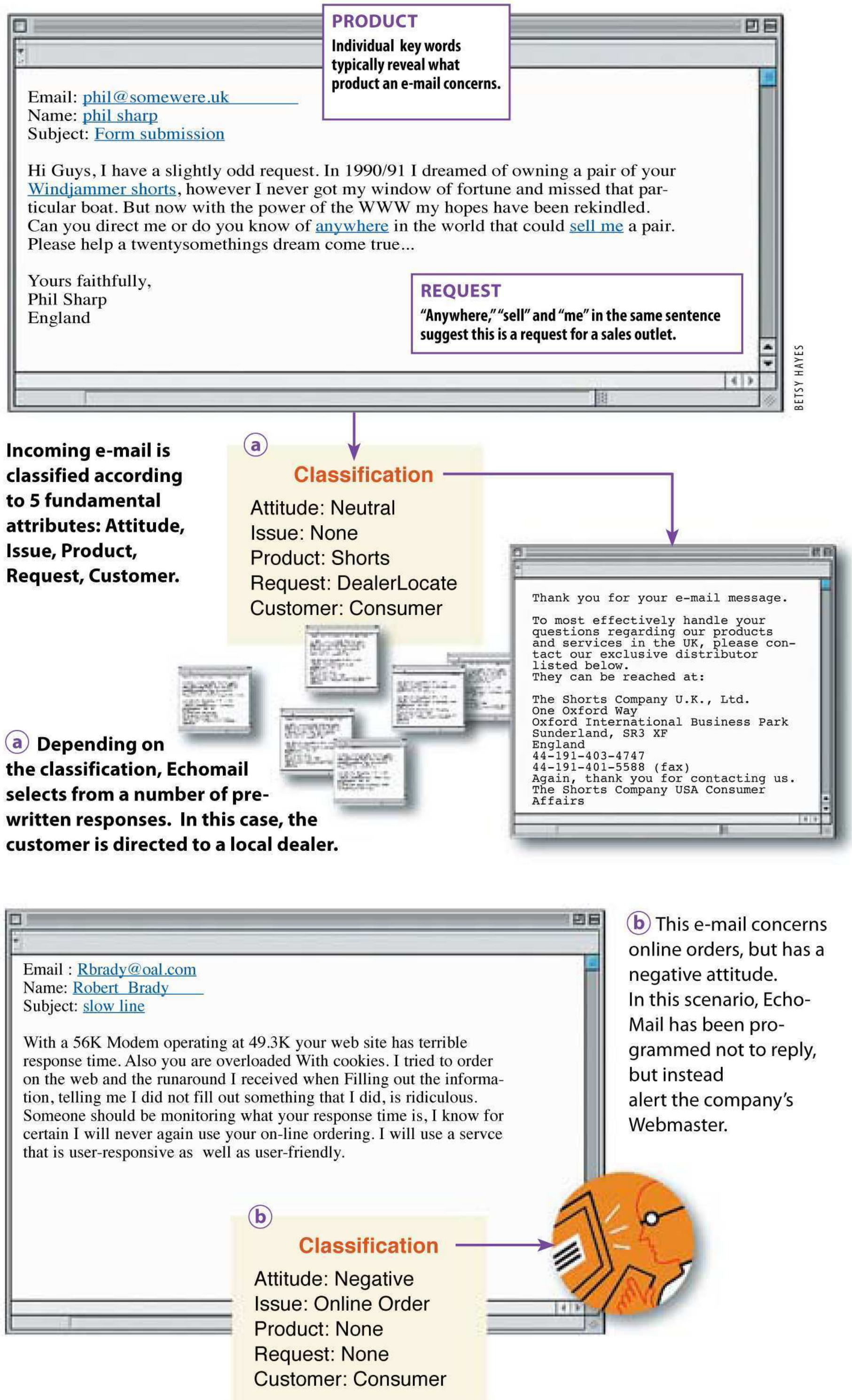
WHEN WE WRITE E-MAIL, WE can be thoroughly, emotionally human. It is, after all, a medium that allows for creativity, opinion and bad grammar. On a visit to Nike's glamorous Web site, for example, someone might start typing a message about how their sneakers fit, then go on about Nike's girls' soccer club and the company's labor policy. Yet despite what can be a clutter of ideas and emotions, Shiva says the foundation for decoding e-mail is that "human communication is not as diverse as we think it is." EchoMail, which handles Nike's customer e-mail, scans these free-form messages for key words and phrases that characterize what Shiva has found are "five fundamental properties" of interest to a company in any e-mail.

"One is the *issue,*" he explains. "Is the e-mail about a billing problem or merchandise return, or a legal problem?"A second fundamental is the *request* the writer is making—say the location of the nearest outlet—and a third is which *products* are involved.

EchoMail's job is to score every e-mail in each fundamental dimension. According to General Interactive's director of semantic research Roland Westgate, EchoMail does this by applying a dictionary of key words and word relationships known as a "semantic network." For instance, "if the program finds the word 'Web site' and 'problem' in close proximity, it might conclude that the e-mail's issue is an online ordering problem." Depending on how an e-mail gets classified, EchoMail can choose either to reply from a selection of prewritten responses (Westgate says most companies maintain a stable of

How Smart Software Sorts E-mail

General Interactive's EchoMail software classifies e-mail by scanning for key words and word combinations. Retailers are using the software to route and automatically answer messages.



10-50 canned replies to common requests and complaints) or forward the e-mail to one or more departments for humans to address.

A fourth basic property is *customer type.* E-mail writers often give away such information as whether they own a boat; they may provide their home address and zip code. EchoMail can scoop up and add this information to the client's customer databases.

The last of Shiva's e-mail fundamentals is *attitude.* EchoMail can classify the writer as either negative, neutral or positive by honing in on key words such as "terrible" or

"superb." Shiva recalls that one client's messages included the words "da bomb." "EchoMail initially classified it as negative," Shiva says. "Then we learned 'da bomb' means 'you're cool' and we changed the classification." At JCPenney, supervisor of Internet customer relations Christine Thomas says all e-mail with a negative attitute rating get checked by a person to ensure that replies going out to upset customers are appropriate.

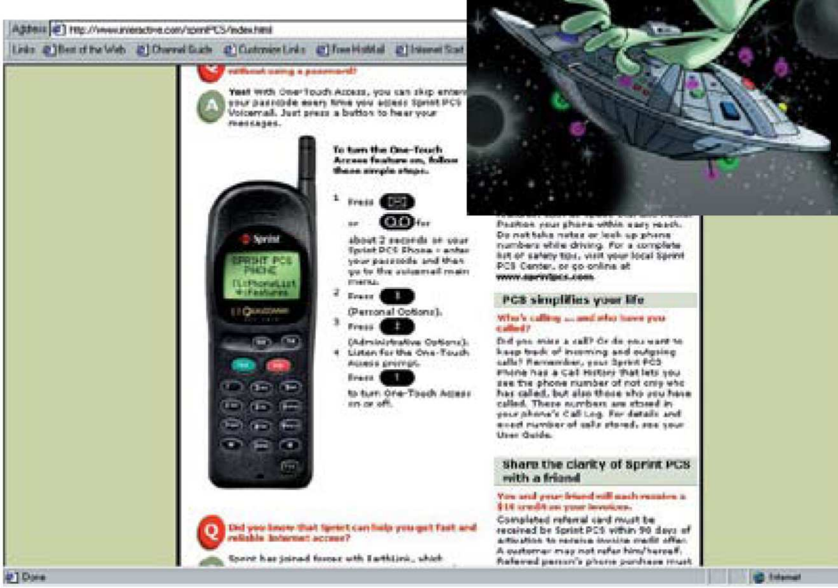
The Message is the Medium

SENDING THE RIGHT SIGnals to customers online is crucial to retailers such as JCPenney, a $30 billion a year business whose 1,148 storefronts have been struggling, but which saw better than expected online sales of nearly $70 million in 1999. Building relationships online is key to the company's future, say executives, and JCPenney has created one of the better retail sites on the Web. Its huge online catalog has images of 10,000 items, and gets 1 million hits per week.

Eighty percent of JCPenney's customers are women, shopping mainly for clothes for themselves and their families, as well as for gifts and household goods. The home page highlights clothing such as camisoles and pantsets, letting a visitor link to a closer view and size chart. Next to the picture of the item, visitors are invited to "Send a productgram to a friend!" General Interactive's EchoMail also handles this feature, sending the friend a picture, product description and a link back to the JCPenney site. The retailer gets the friend's e-mail address, and a potential new customer.

The site encourages customers to interact. For instance, by clicking on a store department such as Home and Leisure, visitors can send e-mail asking advice on home decorating, which EchoMail routes to the appropriate department for a human reply. E-mail to the maternity site contain "all sorts of personal questions," according to Thomas. From the home page one can join clubs such as "Just 4 Me," where larger women can size and select clothes, or link to a Lucas-owned Star Wars page to play games and order theme merchandise.

The site's goal is to "surprise and delight" visitors, explains Ron Hanners, executive vice president of JCP Commerce Solutions, the retailer's e-commerce arm. As the visitor moves through links, he says "the experience should become an emotional surge" that leads to a purchase. But the sale is only "the first part of the loop," according to Hanners. He says JCPenney must make a "return loop" by speaking back to that customer, "offering them additional products at a fair price and added convenience."



Click-through commerce: A Sprint ad and a concept piece designed by General Interactive depict the next wave in direct marketing—colorful, interactive e-mail messages.

According to Paul Sonderegger of Forrester Research, direct e-mail marketing is shaping up as a powerful way to close the customer loop. A survey by Forrester of 47 marketing managers ranked Web banners and buttons as least effective in drawing visitors to a site, while e-mail to customers' inboxes was ranked most effective. And though "simple campaigns" with text e-mail now predominate, Forrester found doubled response rates from graphical e-mails in HTML format. With interactive e-mail, says Sonderegger, companies "are in effect initiating a conversation with the customer. When that customer responds, they are engaged in a dialogue." That dialogue can turn casual surfers into repeat customers. Hanners confirms that the JCPenney site gets "two or three times greater" response from e-mail promotions than from online ads.

Hanners says EchoMail also saves money by "multiplying our personnel's effectiveness." At the time of the "Ellen" furor, JCPenney received about 1,200 e-mails per month. By late 1999, the number had grown to 30,000. Yet the Internet customer service staff run by Thomas still numbers just four people. Back in Cambridge, General Interactive staff have conducted time-motion studies that show the cost for humans to read and compose an answer to a single e-mail averages $4.23. Shiva's company charges a fee of $100,000 or more to set up and customize the system—which the client leases and runs on General Interactive's servers in Waltham, Mass. After that, General Interactive gets paid between 50 cents and $1 for each message successfully decoded and replied to automatically. The client, according to Shiva, saves at least $3 per message.

Dr. E-mail's Corporate Brain

WITH AROUND 100 BILLION E-MAIL messages flashing through the ether each year, there is clearly plenty of money to be made handling them, and Dr. E-mail's practice is seeing heated competition *(see "Companies Answering E-mail" on p. 47)*. According to International Data Corp.'s Mark Levitt, General Interactive now controls an estimated 22 percent of the automated e-mail response market, with revenues in the neighborhood of $17 million. But the firm's principal rival, Brightware, has been burning up the track and is now tops in revenues. And Kana

Companies Answering E-mail

Leaders in the electronic customer relationship management (CRM) industry are selling software to automatically read, route and reply to messages.

COMPANY/LOCATION/FOUNDED/STATUS	URL	HIGHLIGHT
Brightware (Novato, Calif.) 1995, private	www.brightware.com	Leads the intelligent e-mail field with an estimated $18 million in revenue.
eGain (Sunnyvale, Calif.) 1997, public	www.egain.com	Clients include America Online, Petopia and WebMD.
HNC Software (San Diego, Calif.) 1986, public	www.ehnc.com	Aptex subsidiary sells SelectResponse automatic e-mail response software.
General Interactive (Cambridge, Mass.) 1994, private	www.interactive.com	Specializes in intelligent e-mail response and creative design for direct marketing.
Kana Communications (Palo Alto, Calif.) 1996, public	www.kana.com	Kana's stock market value jumps to $170 million the day of its September 1999 IPO.
Lucent Technologies (Murray Hill, N.J.) 1995, public	www.lucent.com	Piloting CRM Central 2000 system for handling e-mail, voice, fax and paper mail.
Mustang.com (Bakersfield, Calif.) 1986, public	www.mustang.com	Software autoanswers e-mail and can prioritize message traffic.
Nortel Networks (Brampton, Ont.) 1895, public	www.nortelnetworks.com	Now testing Symposium Web Response Server for routing e-mail to call center agents.

Communications, which raised $50 million in an initial public offering (IPO) last fall, boasts the largest number of clients overall. Shiva says an IPO may also be in the offing for General Interactive.

In the long run, the most successful e-mail managers could be phone giants such as Nortel Networks, GTE and Lucent Technologies. The latter handles 150 million voice mail boxes at 150,000 locations in 90 countries, and owns 24 percent of the $175 million world market in "unified messaging"—the ability to access phone, fax and e-mail messages from any number of devices on any network. Donna Fluss, an analyst with the Gartner Group, says the winners in e-mail response will be those who can integrate e-mail with call centers and paper mail. From the customer's viewpoint, "if I send an e-mail and telephone, and find the channels aren't integrated, that's hard for me." To the company, "value increases exponentially as [e-mail] is integrated into the service environment," she adds.

Although stakes for big retailers trying to gain market share online could not be higher, many have barely started to figure out the medium. Taylor's survey of 1,000 companies' online efforts found in 1999 that 60 percent did not even have e-mail addresses on their sites. Taylor believes that is because "their boards don't have people who understand the medium and their IT departments are disempowered."

In his office over Sage's grocery, Dr. E-mail tells of his own experiences educating these giant firms about how, taken together, EchoMail's capabilities to route, respond to and reach out by e-mail actually consititute an "RMOS," or Relationship Management Operating System. The RMOS is Dr. E-mail's latest pitch. Think of it, he says, as a synchronized, real-time corporate nerve center for winning and keeping today's impatient online customers—one that tracks what they are are buying and thinking, and helps a company respond to their changing needs.

If the reply looks and feels "human," will we mind that we've been answered by a machine?

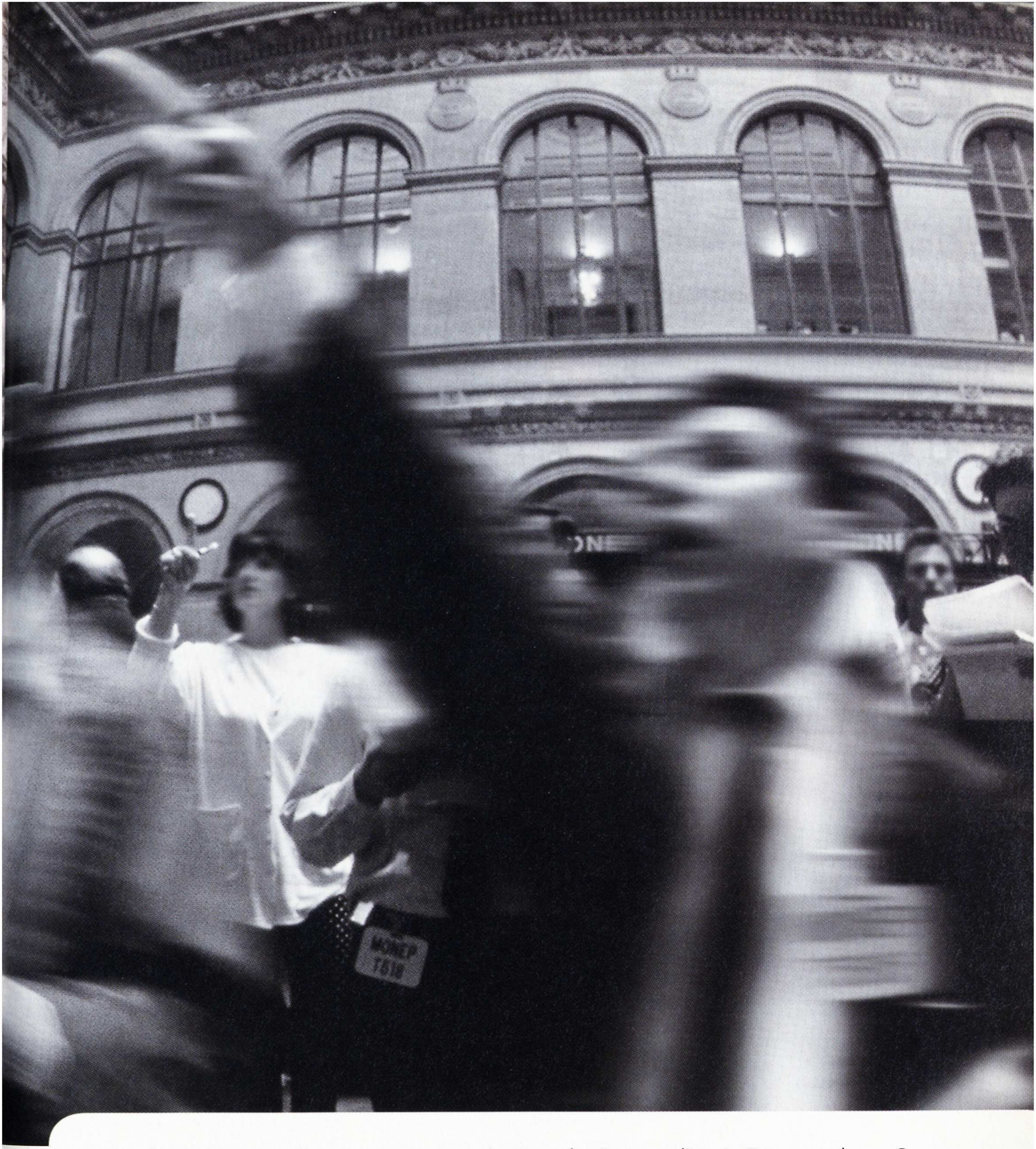
When a TV monitor in the room refuses to play a video Shiva wants to show, he grabs a blue felt marker and rushes to the whiteboard, drawing and talking at once. Each company has two parts, like a human brain, he explains. The blue marker draws lobe-like shapes, a large one on the right, a smaller on the left—the brain of an Ur-company drifting through the whiteboard of 21st century cyberspace.

"Here are customers coming in from outside," says Shiva, flicking the pen to make streaks pointing at the blue brain. "They have contact with marketing, the creative people, the customer care people, PR—like the right brain over here. Here in the left brain are all the rational parts—order fulfillment, manufacturing, finance, legal—all that stuff." He sticks half of corporate America in the lobe, double outlining it.

While some companies are very good at left brain, rational tasks, they don't do outreach well. Others excel at intuitive and creative right brain tasks such as PR and branding, but fumble the back office work. E-commerce, experienced through the medium of e-mail, Shiva argues, is so swift and volatile it will force companies to make the two sides of their brains work together as never before, in order to communicate with the world in a way that builds trust and loyalty. Hatching big blue crosses between the lobes, Shiva shows the RMOS knitting together corporate divisions just as the fibers of the corpus callosum link the hemispheres of the human brain. "We're at the convergence of a bunch of old industrial experience, new media, art and technology, traditional sales and information technology," says Shiva. "That's the way future companies will be built."

And not just companies. He pushes across the table a clipping from *The Boston Globe* announcing that the U.S. Senate has signed up for EchoMail. "As far as the Senate is concerned, 'Dr. E-mail' is In," reads the headline. One day soon, perhaps, those bland, generic "Dear Constituent" replies will be replaced by rapid-fire e-mail as helpful and accountable as any from Citibank or JCPenney.

If those replies are good enough—that is, if they seem human in their look and feel—will we mind that we were answered by a machine? ◊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If biologists can learn to use devices only a few billionths of a meter across, they could get a far better view of life's processes. They may even find ways to tinker with the machinery of life, death and disease. Welcome to the world of "nanomedicine." As this story and the next one reveal, it's closer than you think.

Quantum Dot Com

Brightly glowing "quantum dots" mean a new way to identify viruses and genes and explore the workings of the cell. Quantum Dot Corporation aims to market these mysterious particles. BY DAVID ROTMAN

With the company's name and logo taped to the glass door, the unpacked boxes, an empty reception desk, and young scientists bustling about, it could be any Silicon Valley company in the chaos of starting up. But this, it quickly becomes apparent, is not an ordinary startup. You begin to notice the difference a few doors past the coffee maker. Just down the hall, in a windowless room lit by the faint glow of a green laser shooting through a maze of optical equipment, you'll find the company's crown jewels, tiny particles emitting a variety of colors. These are quantum dots—crystals made up of only a few hundred atoms. Viewed through an ordinary optical microscope, they twinkle like stars in a moonless sky.

Quantum Dot Corporation—and its handful of high-profile venture capital investors—is betting these glowing specks will change how biologists view the cellular world. The particles measure only a few nanometers (billionths of a meter) across. Because this is about the same size as a protein molecule or a short sequence of DNA, quantum dots could be near-perfect beacons for lighting up biological events. They come in a nearly unlimited palette of colors and can be linked to biomolecules to form sensitive probes to identify specific

SOURCE: J. LEE, K. JENSEN, M. BAWENDI.

PHOTOGRAPH BY FELICE FRANKEL
PORTRAITS BY ANNE HAMERSKY

Pure color: Quantum dots embedded in millimeter-long rods of polymer show off the nanoparticles' range of colors.

compounds and track biological events.

Fluorescent tags are ubiquitous in medicine and biology—used in everything from HIV tests to imaging the inner functions of cells. But the dyes that biologists now rely on have serious drawbacks. For one thing, different types of dye molecules must be used for each color, and a matching laser must be used to get a dye to fluoresce: a green laser for a green dye, yellow for a yellow dye, and so on. The colors emitted by the dyes tend to bleed together, and using a combination of lasers is unwieldy. These limitations mean that, in practice, you cannot look for more than a few types of biomolecules at a time. What's more, dyes fade quickly, so imaging is a one-shot affair.

Quantum dots have none of these shortcomings. You can make sharply colored dots simply by varying the size of the nanoparticles and make a rainbow of these colors fluoresce with white light or a single-color laser. Furthermore, the nanoparticles continue to shine for much longer than dyes do. These improvements allow you to simultaneously tag various biological components—say different proteins or various sequences of DNA—with specific colored nanodots.

That kind of flexibility could mean a cheap and easy way to screen a blood sample for the presence of a number of different viruses at the same time. It could also give physicians a quick take on a patient's condition. For instance, the presence of a particular set of proteins is a strong indicator that a person is having a heart attack; quantum dots could offer a rapid and simple test to detect these proteins. On the research front, the ability to simultaneously tag multiple biomolecules could provide a powerful way to watch the complex cellular changes and events associated with diseases, providing clues for drug discovery.

Dot of the Iceberg

THE CHALLENGE, OF COURSE, LIES in transforming this raw scientific potential into a viable business. That's where Palo Alto, Calif.-based Quantum Dot comes in. Like any other fledgling technology company, it has to attract financial backing by wowing investors and working out a viable business plan—as well as fending off emerging competition by building up a strong technology portfolio *(see "Quantum Competition," p. 57).* But for Quantum Dot the challenges go beyond those for a typical startup. Not only does it want to succeed commercially, it wants to do so by going where few companies have gone before: using nanotechnology (manipulating and building materials on the nanometer scale) as a tool in medicine and biology.

Even in basic research, let alone in the commercial world, the interface of nanotech and biology is largely uncharted territory. Quantum dots have intrigued physical scientists seeking new kinds of electronic and optical devices for more than a decade, but few biological researchers gave them a second thought. To succeed, the startup company has to bring together biotech and nanotech. Adding to the difficulty, most venture capitalists—whose backing these days is critical to almost any startup—have displayed an aversion to anything as esoteric sounding as nanotechnology. They may rush to fund dot-com startups, but put the word "quantum" in front of the word dot and eyes begin to glaze.

Those forming Quantum Dot, however, are betting that the potential of this cutting-edge technology will ultimately make those glazed eyes snap into focus. The company is co-founded by a pair of consummate Silicon Valley insiders, Joel Martin and Bala Manian, who between them have helped launch a half-dozen technology companies in the fields of medical devices and instrumentation. Within Quantum Dot's first eight months of existence, the entrepreneurial pair had raised $7.5 million in venture funding. CEO and president Martin says getting investors excited is a matter of timing: Catching a technology just as an explosion of scientific advances brings it to the edge of commercial practicality. "You have to have something that will be on the market in the next couple years," says Martin. "It can't be so far out that it's on the bleeding edge." At the same time, he adds, "it's important that the technology captures people's imagination."

The Coolness Factor

THREE YEARS AGO, MARTIN, A physical chemist turned entrepreneur and venture capitalist, had a million dollars to spend and went shopping for just such a technology. Fresh from a stint as CEO of Argonaut Technologies (a company he co-founded that makes instruments used in the discovery of new materials and drugs), Martin was financially backed by Menlo Park, Calif.-based Institutional Venture Partners and, as he recalls, given the simple directions: "Go find it." The "it" was a hot new technology that could be turned into a successful business.

For the next eight months, Martin pored over almost 100 ideas. Most, he says, fell into the "so what?" category—technically workable but with dubious potential markets. Others were "Buck Rogers sort of ideas from an investor's perspective. They were so far from commercial reality, they were impractical. No one wants to spend 15 to 20 years to *maybe* have a technology that works."

> Joel Martin was guaranteed a million dollars in venture capital backing and told to "go find it." "It" was a hot new technology.

Martin's instinct gave him straightforward advice on what investors would buy: "a technology that was commercializable, had a big market and had modest technical risks. But we still wanted to have something that was cool and sexy." Quantum dots fit the bill. Physical scientists have thought these nanoparticles were cool since the mid-1980s when work at Bell Labs began unlocking their mysteries and establishing consistent synthesis methods. From the viewpoint of fundamental science, these semiconducting crystals are fascinating because such inorganic materials do not normally exist in the form of tiny particles. In bulk semiconductors, for example, atoms are bound in a solid; quantum dots, however, are small groups of atoms that exist as individual particles about the size of a large molecule. The dots created at Quantum Dot and elsewhere are made of the semiconductor cadmium selenide, but many other material possibilities exist.

It turns out that quantum dots aren't just intriguing science; they're also interesting from a technology perspective. Because nanodots are so small, they are governed by the quirky rules of quantum mechanics (hence their moniker) that dictate the behavior of atoms and molecules. One result of such "quantum-size effects" is that the size of the dot dictates the wavelength (and color) of its fluorescence. A 2-nanometer particle glows bright green; a 5-nanometer particle emits longer wavelengths that we see as red. Making different size nanoparticles to emit a desired color is like fingering guitar strings to produce different notes.

That may be way cool if you're a chemist or a physicist. But to most biologists—and certainly to venture capitalists—quantum dots in the 1980s and early 1990s were just another quirky plaything of physical scientists. The dots were hard to make, didn't shine very brightly—and no one really knew what to do with them anyway. Attempts to use quantum dots as novel electronic and optical materials progressed slowly, in part because it proved extremely difficult to structure them with the precision required for practical devices. Much of the work on quantum dots remained in the realm of basic research, with the scientists motivated purely by a desire to understand the fundamental properties of these odd particles.

In the Glow

By 1997, however, when Martin began shopping for new technologies, several groups of researchers had begun to make quantum dots brighter and more practical. With these refinements, the potential for

Sharper vision: CEO Martin sees a match between nanotech and biotech.

Applications in hand: Chemist Alivisatos has been working on quantum dots since the mid-1980s.

using them in biological imaging and diagnostics was becoming increasingly evident. It began to look as if it would be possible to turn nanoparticles into sensitive probes that would hone in on specific biological targets, all the time glowing in distinctive colors that said: "Here it is!"—with the "it" being a virus, a protein of great interest, perhaps some specific DNA.

The movement toward biological applications was a long process, with no single breakthrough leading the way. But a key realization, says Paul Alivisatos, a chemist at the University of California, Berkeley, who contributed a number of important advances, is that "quantum dots are macromolecules, the size of proteins. Once you realize that the size scales are compatible, you say, "Okay, these things can go together." Adds Moungi Bawendi, an MIT chemist who has worked on the particles for more than a decade: Biology is "not what we initially thought about. But in some sense it's a much better application—it's a natural."

It might be possible to use glowing nanodots attached to proteins or other biomolecules to watch cellular events as they unfold.

Such a natural, in fact, that Alivisatos and collaborator Shimon Weiss, a physicist at Lawrence Berkeley Laboratory, and

graduate student Marcel Bruchez, started discussing business opportunities in the mid-1990s. "We were stumbling" around, trying to form a company to exploit the biological potential of quantum dots, says Alivisatos. Then, in 1997, they got a phone call from Joel Martin, who was wandering around Silicon Valley looking for the new new thing. In a nanosecond, Alivisatos was inviting the venture capitalist—and his million dollar check—to the Berkeley lab for a visit.

The potential of quantum dots was confirmed in late 1998 by the publication of two breakthrough papers in the journal *Science* demonstrating that the nanoparticles could be made compatible with living systems and used as bio-probes. One paper was by Alivisatos and his Berkeley co-workers, the other by Indiana University chemist Shuming Nie. Both groups of researchers had learned how to dissolve the nanoparticles in water and coat the tiny crystals with an outer layer to which they could readily bind biomolecules capable of recognizing proteins or DNA. The research confirmed the potential of quantum dot probes for sensitive diagnostic tests, even genetic analysis.

As part of the research, the scientific teams demonstrated ways to detect proteins inside and on the surface of a cell, suggesting a tantalizing possibility—it might be possible to attach a single glowing nanodot to, say, a protein, as a way to watch cellular events. Such observations could provide a far greater understanding of how cells work—and what can go wrong—providing valuable clues in the development of future pharmaceuticals and therapeutics.

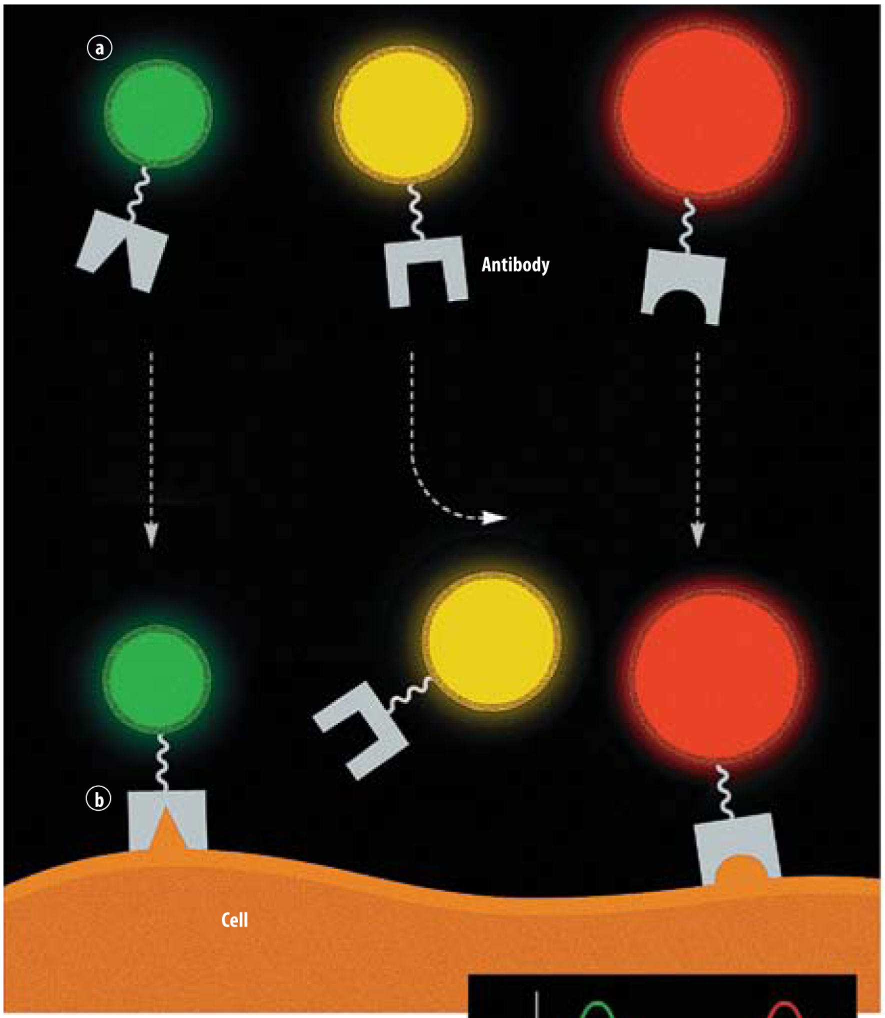
A month after the *Science* papers, Quantum Dot was started. Martin and Manian signed leading nanodot researchers to the company's scientific advisory board and gave them a financial stake in the outfit's success. That meant making partners out of long-time rivals Alivisatos, Bawendi, Nie and Paul Mulvaney, a chemistry professor at the University of Melbourne. For good measure, the startup hired Bruchez and Stephen Empedocles, newly minted PhDs from Alivisatos' and Bawendi's chemistry labs, as staff scientists. The company licensed key technologies from the universities, garnering an intellectual property portfolio covering the use of quantum dots in biology.

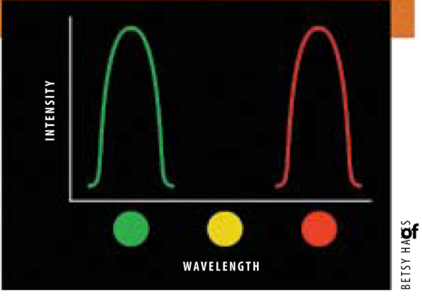
Martin says that while the scientific value of the technology "clicked" the first time he saw it, the path to commercialization was not as obvious. Clearly, the startup didn't want to compete directly with diagnostics and analytical instrument giants such as Roche and Perkin-Elmer, and just as clearly it didn't want to merely supply quantum dots as commodity items. The answer, says Martin, was a business model imitating Intel. The chip maker aims to put its microprocessors in everyone's computer; Quantum Dot would try to make its nanoparticles an essential piece of diagnostics kits and analytical instruments. The strategy was to make the large manufacturers customers, not competitors.

Quantum Dot's business plan calls for the company to begin shipping test quantities of dots to potential customers this winter to allow them to assess the value of the nanoparticles in diagnostic testing and drug discovery. Deals with instrument makers will come later, says Martin.

Q-Dot Diagnosis

Colored nanodots can tag biological markers to profile a cell population.





a By synthesizing quantum dots with an outer silica coating, scientists can readily attach different biomolecules, such as various antibodies, to the different color nanoparticles. b Upon contact with a cell, each antibody binds only to a specific antigen that it recognizes. The presence or absence of each antigen on the cell surface governs which color nanoparticles are captured; the rest are washed away. The spectrum of wavelengths associated with each cell (right) reveals the presence or absence of each antigen in a cell population. This information indicates the presence of a type of cell or the expression of cellular markers associated with disease.

Analysis of the spectrum shows the absence of the yellow nanodots.

Vulnerable position: The startup needs to meet its milestones, says co-founder Manian.

He estimates the startup has enough cash to survive for another year but says it plans to raise more money this spring.

The company expects to have a commercial product by mid-year, and Martin says initial applications will likely come in drug research. But for the longer term, one killer app stands out. Quantum Dot is working on biological "bar codes"—polymer beads packed with a known combination of thousands or even millions of quantum dots. Each of these beads would have a known color signature—a spectral bar code. Instead of using a quantum dot to tag a biomolecule by binding to it, the scientists aim to build assays for genetic analysis on the surface of the beads. "Labs on a chip" are one of the hottest new approaches to genetic analysis, and Quantum Dot hopes its "lab on a bead" could be an easier way to recognize gene sequences. The researchers attach a particular sequence of DNA to the surface of each type of bead. Because you could readily form thousands, even millions, of beads each with a distinct DNA probe (and readily identify each probe using the bar code), the technique could provide a quick way to simultaneously identify a large number of gene sequences in, say, a blood sample, providing a valuable diagnostic and research tool.

When Cool is not Enough

Despite their early success in raising money, Quantum Dot's founders are aware that the company is entering a do-or-die period. Without a blockbuster product in the immediate future, the

company is in a vulnerable stage common to many startups. "Every opportunity has a time window. There are always competing technologies," says co-founder Manian. "We may be successful in three years, but if someone has come up with an alternative in two years, the train will have already left the station." Manian says the company has milestones. "Looking at the barriers you encounter, you make subjective calls: Will it be solved in a week or will it take two years? If it will take two years, you immediately need to look for alternatives or a safety net." The coolness factor, he warns, "will wear off very quickly if you can't support it with economic benefits. It has to result in real-world applications."

This sense of urgency in developing uses for the nanoparticles has drawn some of the best and brightest young quantum-dot scientists to the company. In Quantum Dot's optics lab, 30-year-old Stephen Empedocles is clearly in charge. This is the company's showcase, where potential investors come to be awed. But Empedocles confidently stands by, inviting a visitor to take a look through the microscope at the single particles, not much larger than a few atoms, glowing brightly. It's a glimpse of the nanoworld that's sure to catch the fancy—and perhaps the checkbook—of an investor.

But the experimental apparatus criss-crossing the lab table like a maze betrays the fact that this is still cutting-edge science. Empedocles joined Quantum Dot immediately after graduating from MIT last spring with a doctorate in chemistry. Already a recognized expert in the development of analytical techniques to detect single quantum dots, Empedocles could have taken a job at a large research organization or had his pick of any number of academic positions. But he was drawn to the challenges and opportunities of taking the fundamental science of quantum dots and using the technology to make an impact on the real world.

"Even at MIT," says Empedocles, "people couldn't figure out why [he would join a risky, new company.] No one else I knew went to a startup." The reason is that the entrepreneurial culture that has taken root in computer and biotech research remains embryonic in the physical sciences. Yet if Quantum Dot succeeds in its quest to marry nanotech and biotech, Empedocles may find that his colleagues at MIT gain a new understanding of his career leap. ◊

The new view of the nanoworld provided by quantum dots has captured the fancy of investors, but it's still cutting-edge science.

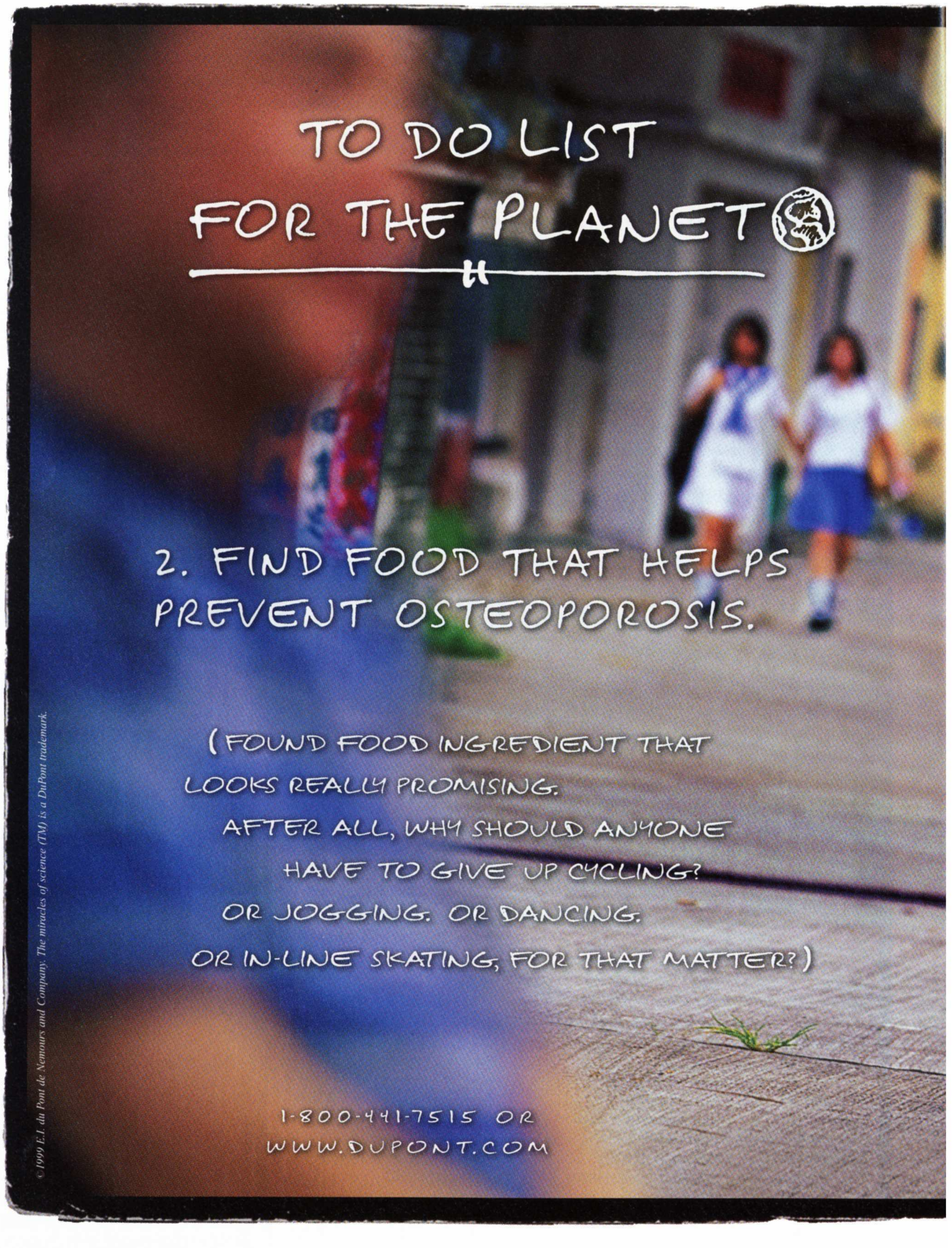
Quantum Competition

Quantum Dot and its scientist backers are not the only ones to see the bright lights of nanoparticles and think biology. A handful of startups have formed during the last several years aiming to exploit the unique properties of nanoparticles in medicine, with objectives ranging from improved diagnostics to more effective drug delivery. Beyond a common attraction to tiny particles, several of these companies share another characteristic—they've been launched by leading university chemists in a hurry to turn recently acquired nanomaterial expertise into a business.

Take Nanosphere. Brainchild of Northwestern University chemists Chad Mirkin and Robert Letsinger, the company has developed a sensitive detector using DNA attached to nanoparticles of gold. When these DNA probes bind with a targeted sequence of genetic material from, say, a particular virus, individual probes form a web and change color, since in their dispersed form the nanoparticles are red and in the aggregate they're blue. The result is a simple and easy to read technique for detecting particular sequences of DNA. An assay using the technology could be ready for commercialization this spring, according to Mirkin. An advanced version of the technology that is being developed is so sensitive to minute amounts of genetic material, says Mirkin, that it doesn't require much of the elaborate sample preparation that's often required in diagnostic testing. "We could have a kit for just about any disease you like," says Mirkin.

Others are exploiting the solubility properties of nanocrystals. Some compounds could be useful drugs except for the fact that they don't dissolve easily in water—and hence they're difficult for the body to absorb. In the form of nanocrystals, however, many of these compounds can be easily dissolved. What's more, it's possible to further modify these tiny particles by attaching additional molecules to their surfaces. The result could be "smart" nanoparticles able to seek out specific biological targets—for healing purposes, or to destroy a pathogenic invader.

COMPANY	FINANCING	STRATEGY
Auspex (Palo Alto, Calif.)	None	Metal nanoparticles for biological imaging and diagnostics
Biocrystals (Westerville, Ohio)	Privately owned	Biological imaging using quantum dots; technology licensed from MIT
Nanomat (Dublin)	$4 million raised in a first round of venture capital	Develop nanocrystals of potentially useful therapeutic compounds
Nanosphere (Evanston, Ill.)	Expect to raise $3 million through a first round of venture financing this winter	Attaching DNA to nanoparticles of gold and to quantum dots for use in diagnostic assays
Quantum Dot (Palo Alto, Calif.)	$7.5 million raised through venture capital. Expect a second round this spring	Attaching DNA and proteins to quantum dots for diagnostics and biological imaging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Nanomedicine Nears the Clinic

Minuscule "smart bombs" that find cancer cells, kill them with the help of lasers and report the kills. Sound crazy? Guess again. That treatment scenario may be less than a decade away. BY DAVID VOSS

THE DEATH LAST FALL OF A 17-year-old patient at the University of Pennsylvania Medical Center shocked the medical research community *(see "A Death in Philadelphia, p. 94)*. The young man, who suffered from a rare genetic defect that stopped his body from metabolizing ammonia, was undergoing an experimental form of treatment called gene therapy. In theory at least, it should be possible to treat a number of devastating diseases by patching in bits of DNA to repair defective or missing genes.

In practice, gene therapy remains difficult and the methods crude. One problem is in sneaking the new genetic material into the cell and getting it incorporated into existing DNA without the individual's immune system going berserk. Most approaches rely on nature's masterful Trojan Horse, the virus. In the case of the patient at Penn, researchers injected very high doses of a modified form of the common cold virus directly into his liver. Once inside, the viral particles were supposed to insert replacement DNA into tissue cells so his liver could start to process ammonia normally. Four days later the patient was dead from multiple organ failure, and speculation centered on the possibility that the immense and sudden injection of the virus caused an overwhelming immune response.

Medical researchers have been terrified of just this scenario since human gene therapy experiments began a decade ago. Now that it's happened, their motivation to find safer alternatives for delivering genes to human cells has been redoubled. Enter nanotechnology. The fabrication of objects and devices on the scale of nanometers has been making rapid progress in the physical sciences *(see "The Hope & the Hype," TR March/April 1999)*. But you wouldn't necessarily think of it in connection with medicine. Yet nanotechniques might offer a solution to current problems in gene therapy—and some remarkable advantages in treating stubborn diseases such as cancer and diabetes.

A small vanguard of medical explorers is exploiting the tools of nanotechnology to manipulate biomolecules that regulate life and death, illness and health. The key to these efforts is that researchers are learning how to tailor devices and materials on the

Tree of hope: Tomalia (left) and Baker are championing highly branched polymers for safer gene therapy.

scale of billionths of a meter, thereby acquiring the ability to engineer structures and machines no bigger than biomolecules such as DNA. They're finally playing on the size scale of biology itself. And that means they may be able to design tiny tools to safely and effectively fix the nanoscopic machinery of illness, just as a mechanic works on a car's engine using tools that are on the same scale as the engine. This may sound like science fiction—and until recently it was—but it's reaching the verge of possibility because teams of doctors and scientists are combining advances from biology and chemistry with the synthesis and fabrication tools from chemical engineering, even the microchip industry.

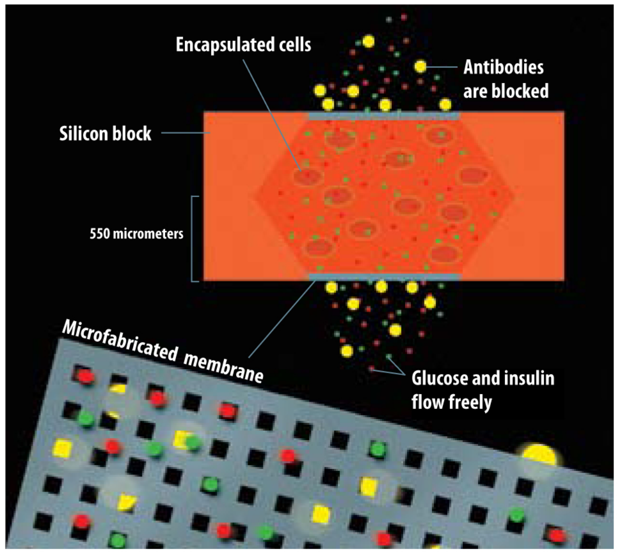
One believer in "nanomedicine" is James Baker, chief of the allergy and immunology department at the University of Michigan's Medical School. He might seem an unlikely champion of nanotech in medicine, a field that has more often been associated with sci-fi notions of tiny machines cruising the human body than with clinically feasible treatments. But Baker is convinced that the tools of nanotechnology will eventually provide a far safer and more effective way to repair genes. So convinced, in fact, that last year Baker founded the University of Michigan's Center for Biologic Nanotechnology, bringing doctors and medical researchers together with chemists and engineers to turn nanomedicine from a futurist dream into clinical reality.

For Baker, the attraction to nanostructures is that these nonbiological substances can be constructed so that they will not trigger an immune response. Years of immunology research has convinced Baker that viral methods are fraught with trouble,

because of the severe immune reaction they trigger. “That started me thinking about synthetic systems,” says the Michigan immunologist. In particular, Baker began to wonder if a novel type of polymer called dendrimers—tree-shaped synthetic molecules that can be engineered on a nanometer scale—could be used to slip DNA covertly through immune defenses into target cells. Dendrimers were invented two decades ago by Baker’s colleague and scientific director of the new center, polymer chemist Donald Tomalia. Since then, dendrimer research has exploded, with researchers pursuing applications from drug delivery to medical imaging.

What sets dendrimers apart from other polymers is their precise nanostructure. Dendrimers form nanometer by nanometer, so the number of synthetic steps dictates their exact size. Their surfaces can be made to form a dense field of molecular groups that serve as hooks for attaching other useful molecules. Dendrimers can also carry internal molecular baggage. These properties could make dendrimers excellent transporters for sneaking DNA into cells. Scientists decorate the dendrimer molecule with the DNA, which scrunches down on the polymer’s surface. The dendrimer-DNA bundles are injected into the tissue; dendrimers of just the right size trigger a process called endocytosis in which the cell deforms to let the DNA-dendrimer package in. Once inside, the DNA is released and migrates to the nucleus where it becomes part of the cell’s genome.

While the research is still in its early stages, initial results suggest that these synthetic nanomaterials just might be a safer alternative to viral transporters for gene therapy. So far, building on work done at the University of California, San Francisco, in the early 1990s, Baker and his Michigan colleagues have shown in lab experiments that they can use dendrimers to efficiently transfer DNA into the cell’s genes. They are now conducting animal trials with rats and mice to demonstrate that the dendrimers don’t cause toxic side effects and to see exactly how efficient dendrimers can be. The next step will be to carry out similar studies in humans to assess the promise of dendrimers for fixing genes. Then the arduous process of setting up actual experiments must begin, involving approval by a special advisory committee at the National Institutes of Health and the Food and Drug Administration. With perseverance, Baker hopes to see clinical trials of dendrimer gene therapy in two years.



BETSY HAYES; SOURCE: UNIVERSITY OF MICHIGAN MEDICAL SCHOOL

For treating diabetes, devices can be built with nanopore membranes. Transplanted pancreatic cells are shielded in a silicon block with nanometer holes large enough to let glucose (red) and insulin (green) flow freely, but too small to allow antibodies (yellow) to enter and attack the foreign cells.

Much of biology happens at a nanometer scale. Biomedical researchers are just beginning to learn how to play on this very small field.

The Real Action

BAKER’S EFFORTS MAY OR MAY NOT pay off in a breakthrough for gene therapy (the field is littered with promising strategies that never panned out). But whether this specific approach is successful or not, it reflects an extremely important development in medicine on the very smallest scale. A typical human cell, like the red blood cells that course through your veins, is five micrometers in diameter. But much of the real action in biology occurs at a considerably smaller level. DNA, for example, is less than three nanometers in diameter—about 100 times smaller than the cell. Many common proteins are only a few nanometers across.

Biomedical researchers have never been able to play effectively on a field this small. To do so now, they are importing techniques and expertise from other areas. Semiconductor manufacturers have been making features on silicon chips only a few hundred nanometers across for several years. Mauro Ferrari, among others, is taking these fabrication techniques and applying them to medicine. A professor of internal medicine and mechanical engineering at Ohio State and director of the university’s new biomedical engineering center, Ferrari has made tiny silicon capsules that can hold healthy cells to replace ones that are not functioning; if, say, the pancreatic cells of a diabetes patient are not working, capsules containing replacement cells can be implanted beneath the patient’s skin. Supplying new cells to the body could be a very valuable way to treat certain diseases such as those caused by enzyme or hormone deficiencies, and various medical researchers have been wrestling with the strategy for years. But as in gene therapy, immune reactions are a major problem. Replacement cells are foreign to the body and are therefore attacked by the body’s immune system, with disastrous results.

But Ferrari has come up with a scheme to swindle the immune system using the tools of nanotechnology. When the immune system sees something foreign, it dispatches antibodies to attack it. If, reasoned Ferrari, you could block the antibodies using an artificial barrier, the immune system wouldn’t be able to see the transplanted cells. Ferrari fabricated his silicon capsules to include membranes with pores small enough to screen out antibodies—but large enough to let desirable molecules flow in and out. “The bio-

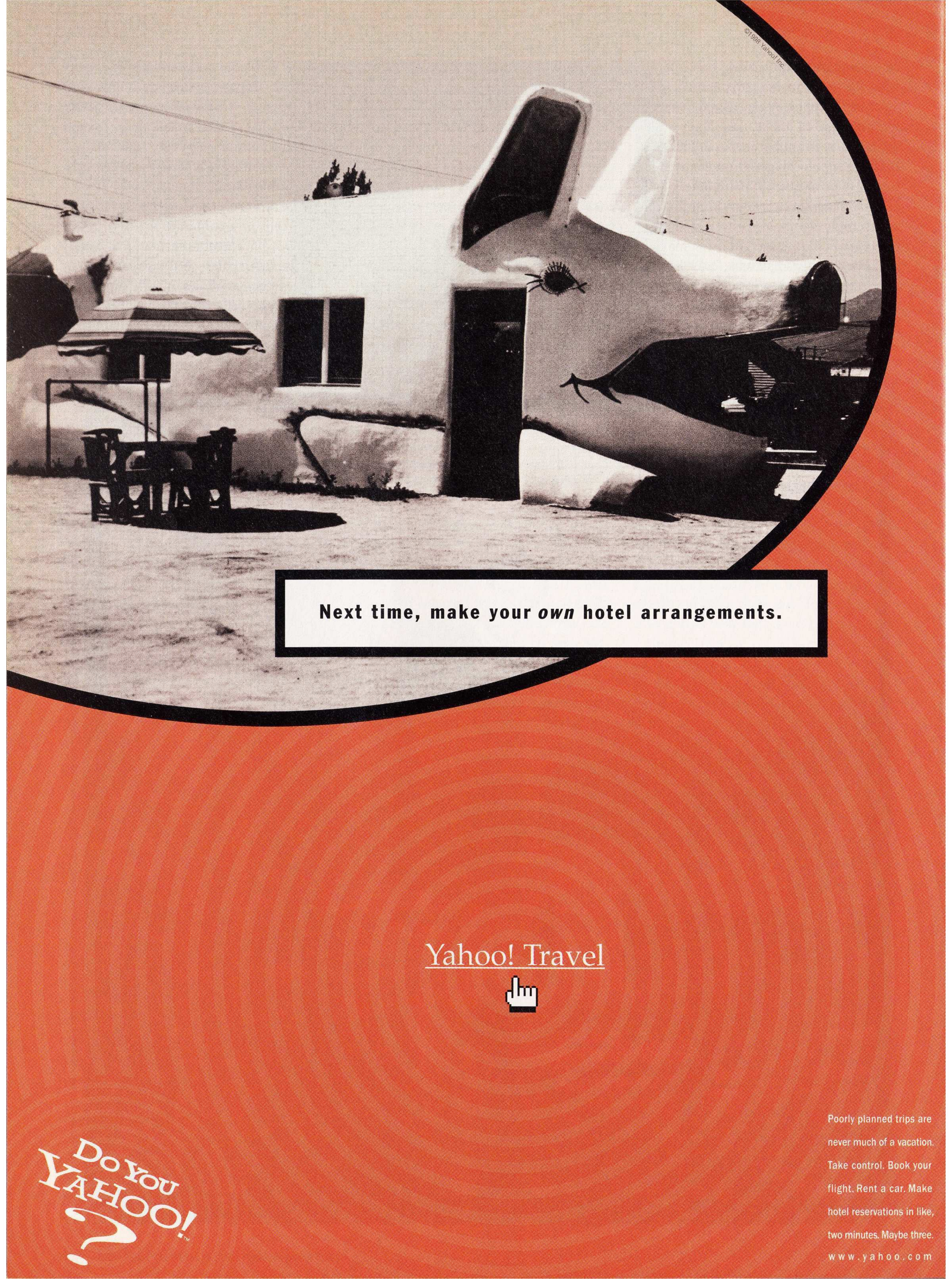
logical recognition molecules don't know what the hell is inside," says Ferrari.

The concept is elegant. But in practice, it's not easy to make nanoholes small enough to keep antibodies out. It turns out that antibodies can get through anything larger than about 18 nanometers (the exact size is still uncertain). Photolithography tools for making state-of-the-art integrated circuits are good for making features only as small as a few hundred nanometers. By adapting these methods used in the semiconductor industry, however, Ferrari managed to create holes only a few nanometers wide.

Technology in hand, Ferrari is launching his attack on a pressing medical problem: diabetes. In one form of the disease, the cells in the pancreas that normally produce insulin do not function properly. The most attractive cure would be to implant fresh copies of the body's tiny glandular insulin factories (called islets of Langerhans) into the body. These would replace the broken pancreatic machinery and restore the body's delicate feedback loop. Such new tissue, however, must be harvested from a compatible nonhuman species. "You would want to use pig islet cells," says Ferrari, "but then your immune system would go crazy and destroy them because they are foreign." Previous attempts to transplant foreign cells required that the patient take drugs to suppress the immune response. That strategy, however, can leave a patient dangerously susceptible to infections.

Ferrari's solution is to house replacement cells in a container made with his nanoporous membrane material. Small glucose molecules could stream freely through the nanoholes into the capsule to activate the cells, and the insulin could trickle out to control the blood chemistry. Ferrari says that he has the technology

Behind barriers: Ferrari's nanomembranes protect implanted cells.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Nanotech Gets Centered

CENTER (FOUNDED)	LOCATION	FOCUS
Center for Biologic Nanotechnology (1998)	University of Michigan Medical School	Dendrimers for gene therapy and anticancer drug delivery
Center for Nanotechnology (1997)	University of Washington	Drug delivery, nanomaterials, DNA sequencing
Nanobiotechnology Center (1999)	Cornell University	The interface of nanotech and biology
Biomedical Engineering Center (1999)	Ohio State University	Nanoporous membranes for cell transplants and drug delivery

ready to go. "We've had success in small animals," he says, "but we need to do it in larger animals like dogs. That would be the slam dunk to allow us to go into human trials." What's holding Ferrari back is funding, and he hopes to get enough money to do large animal studies in a year, and possibly human studies in two years.

Ferrari isn't the only one who thinks that cells can be smuggled into the body to restore normal function. Tejal Desai, who is a bioengineer at the University of Illinois and former student of Ferrari when they were both at the University of California, Berkeley (Desai was recently named to TR100's list of young innovators), is investigating the approach for use in the brain—bringing in normal cells that would secrete neurotransmitters. Those neurotransmitters might be able to replace the ones lost when cells are damaged in diseases such as Alzheimer's. Desai is utilizing the same nanopore fabrication technology used by Ferrari to make microcapsules for implanting neurons in the brain. Once the capsules are implanted, the neurons can be electrically stimulated to release neurotransmitters. Eventually, says Desai, this technology "could be used for such applications as treating Alzheimer's or Parkinson's—basically any disorder where the basic neurosecretory-cells are missing or damaged."

Nanomotoring

Making use of materials engineered on the nanoscale is an intriguing approach to medicine. But it's by no means the end of how nanotechnology might ultimately change medical care. Farther out on the nanomedicine horizon, Carlo Montemagno of Cornell University is working on mechanical devices—motors, pumps, all the equipment for a chemical factory—smaller than a living cell. Nanomotors, for example, might ultimately power small mixers to whip up tiny batches of drugs, then pump out the freshly made pharmaceuticals directly to tissues that need them.

The idea of incorporating motors into your body might seem wild—and it is. But it does have the advantage of being inspired, at least in part, by biology itself. Some bacteria, for instance, move by whipping around a tiny tail, or flagellum. The business end of the flagellum is essentially a motor, and, if you took it apart, you'd see a protein rotor nestled in a pocket formed by six proteins in a ring. Each protein is an enzyme called ATPase, which converts the cellular fuel ATP (adenosine triphosphate) into ADP (adenosine diphosphate); the chemical energy released by this reaction is what powers the machine. When the motor is running, the rotor ratchets around this ring of proteins. Beyond that, biologists actually know little of how the thing functions.

But they do know it works. And to fabricate his nanomotor, Montemagno stole from nature, grafting the moving parts from a bacterial motor onto a metal nanostructure. The Cornell team found a way to attach the nanomotors to an array of tiny pedestals on a micromachined nickel surface. The technique works well enough that Montemagno and his co-workers have demonstrated one of these hybrid motors spinning away: Montemagno's team is measuring things like horsepower and motor efficiency, tests that would feel right at home to any mechanical engineer scrutinizing a car engine.

Montemagno envisions that tiny chemical factories could one day operate within a cell. He speculates that these nanofactories could be targeted to specific cells, such as those of tumors, where they would synthesize and deliver chemotherapy agents. This selective targeting and local delivery would reduce toxicity to other tissues and pack a much bigger punch than current therapies. One neat trick the group has achieved is to combine the light-harvesting mechanisms from photosynthesis with the biomotor to make a solar-powered nanomachine. Light energy creates ATP, which in turn fuels the nanoengine. It's the first step to creating autonomous nanodevices that don't need external fuel sources.

Bombs Away

Nanopharmacies like Montemagno's are at the outer limits of medical technology. It will be years before scientists even know if these nanodevices are practical. But long before that, researchers like Baker hope nanotechnology will be making an impact.

One nearer-term project on Baker's agenda is smart bombs for treating cancer. These dendrimer-based devices are designed to infiltrate living cells and detect pre-malignant and cancerous changes. If the dendrimer bomb senses such threatening changes, it will release a substance to kill the cell (in one version, laser light is used to trigger the release of chemical agents from the polymer). Just for good measure, when its work is done, the dendrimer device will be able to verify that the cancerous cell is dead.

That may sound just as far out as the nanomotor, but in the eyes of the nation's preeminent medical researchers, it isn't. Indeed, last fall, the National Cancer Institute gave Baker's center $4.4 million to rig up some smart bombs against cancer. Baker hopes to demonstrate the proof of concept in three years. He predicts that in a decade these microscopic SWAT teams will be in the pharmacy. "Being able to engineer things on the scale of biomolecules is very powerful," he says. So powerful, in fact, that the engineering of the very small could soon pave the way for an entirely different kind of medicine: nanomedicine. ◊

Computing's Johnny Appleseed

Almost forgotten today, J.C.R. Licklider mentored the generation that created computing as we know it.

Often, says Tim Anderson, thinking back to the mid-1970s and his time as a student at MIT's Laboratory for Computer Science, you'd walk into the terminal room and there he'd be: Professor J.C.R. Licklider, typing code with his own 10 fingers.

This took some getting used to. Lick, as everyone called him, wasn't a hacker, but an absent-minded-professor-type in his 60s. "He'd sit there with a bottle of Coke and a vending machine brownie as if that were a perfectly satisfactory lunch," recalls Anderson, who is now the chief technology officer at an Internet startup known as Offroad Capital. "He had these funny colored glasses with yellow lenses; he had some theory that they helped him see better."

Anderson wasn't sure what Lick was working on—something to do with making computer code as intuitive as ordinary conversation, and as easy as drawing a sketch. The programs he wrote weren't so hot, but that almost didn't matter. For Lick the important thing was imagining the future—and an astonishing amount of what we now take for granted owes its origins to his work. He would hold forth for hours in his wry Missouri accent, spinning visions of graphical computing, digital libraries, online banking and e-commerce, computers with megabytes of memory, software that would live on the network and migrate wherever it was needed—all this 10 years before the Macintosh, 20 years before the popularization of the Web.

BY M. MITCHELL WALDROP

What Lick never got around to mentioning was that he had done as much as anyone on earth to make such wonders possible. In fact, the big, rumpled guy in the corner office had laid the foundations for time-sharing, point-and-click interfaces, graphics and the Internet—virtually all of modern computing. "He was clearly the father of us all," says Anderson. "But you'd never know it from talking to him."

Mind Meets Machine

SUCH MODESTY WAS BRED INTO LICKLIDER AT AN EARLY AGE. BACK in St. Louis, where he was born in 1915, a self-satisfied man was said to have too much "side"—a reference to the fatty flanks of a hog. And little Robnett, as Joseph Carl Robnett Licklider was known as a boy, had been raised to think "side" was unseemly. Every evening from the time he was 5, it had been his duty and honor to take the arm of his maiden aunt, escort her to the dinner table, and hold out her chair. Even as an adult, Lick was a remarkably courteous man who rarely raised his voice in anger and who found it almost physically impossible to remain seated when a woman entered the room.

> Licklider believed that humans and computers were destined to unite in an almost mystical, symbiotic partnership.

A happy, energetic boy with a lively sense of fun, Licklider early on displayed an insatiable curiosity and a love of all things technological—especially cars. At 15, he bought an old junker and took it apart again and again, trying to figure out its inner workings. For years thereafter, he refused to pay more than $50 for a car; whatever shape it was in, he could fix it up and make it go.

At Washington University in St. Louis, he wanted to major in everything—and almost did. He graduated in 1937 with a triple degree in physics, math and psychology, with particular interest in deciphering the ultimate gadget: the brain. For his doctoral dissertation at the University of Rochester, he made the first maps of neural activity on the auditory cortex, pinpointing the regions crucial to our ability to hear musical pitch.

Ironically, this passion for psychology would be central to Lick's pathbreaking work in computing. Most computer pioneers came to the field in the 1940s and 1950s with backgrounds in math or electrical engineering, leading them to focus on gadgetry: making the machines bigger, faster and more reliable. But Lick's study of neuroscience left him with a deep scientific appreciation for the human capacity to perceive, to adapt, to make choices, and to create new ways of tackling problems. To Lick, these abilities were every bit as subtle and as worthy of respect as the automated execution of a series of instructions. And that's why to him, the real challenge would always lie in adapting computers to the humans who use them, exploiting the strengths of each.

Lick's instincts in this direction were apparent by 1942, when he joined Harvard's Psycho-Acoustics Laboratory. The Army Air Force was funding a team of psychologists at that lab to attack the problem of noise. The United States had just entered World War II, and aircraft crews were finding it difficult to function amid the overwhelming din of the engines. Lick devised a method for artfully distorting radio transmissions to emphasize consonants over vowels and thus make words stand out against a background of radio static and mechanized cacophony. Already, he was shaping the technology to fit the human, not the reverse.

That sensibility asserted itself even more after 1950, when Lick moved to MIT. Almost immediately, he got caught up in Project SAGE—a crash program to create a computer-based air-defense system against Soviet long-range bombers. The computer in SAGE was Whirlwind, which had been under development at MIT since 1944. Other early computers, such as ENIAC, had started out as giant calculators, with an operating style to match: You entered the numbers and eventually got back a printout with the answer. This came to be known as batch-processing. Whirlwind, by contrast, had started out as a flight simulator and had evolved into the world's first real-time computer: It would try to respond instantly to whatever the user did at the console. The challenge was to prove that a computer could take the data coming in from a new generation of air-defense radars and display the results rapidly in a meaningful form.

The project succeeded. Although high-flying, fast-moving ICBMs had made the air-defense system obsolete by the time it was finally deployed in 1958, SAGE nevertheless served as a model for the interactive, real-time computers that followed—including modern personal computers. Lick headed SAGE's human-factors team, and he saw the project as an example of how machines and humans could work in partnership. Without computers, humans couldn't begin to integrate all that radar information. Without humans, computers couldn't recognize the significance of that information, or make decisions. But together—ah yes, together...

By 1957, the year he left MIT for the nearby consulting firm Bolt Beranek and Newman, that train of thought was leading Lick down strange new paths. That spring and summer, he kept track of what he actually did during the day—with shocking results. "About 85 percent of my 'thinking' time was spent getting into a position to think, to make a decision, to learn something I needed to know," he later wrote. He concluded that his decisions on what work to attempt "were determined to an embarrassingly great extent by considerations of clerical feasibility, not intellectual capability."

Computers, he believed, would rescue the human mind from its enslavement by mundane detail. Human and machine were destined to unite in an almost mystical partnership, with computers handling rote algorithms while people provided the creative impulses. The hope, he said, was that "the resulting partnership will think as no human brain has every thought and process data in a way not approached by the information-handling machines we know today." Lick found this vision of human-computer symbiosis so compelling that standard psychology could no longer compete. "Any psychologist is crazy to keep on working with people if he has access to a computer," he said, only partly in jest.

And so he switched fields. In a 1960 paper called "Man-Computer Symbiosis," published in the *IRE Transactions on Human Factors in Electronics*, Licklider formulated a new vision of computing. He described a machine that humans could relate to in the manner of "a colleague whose competence supplements your own"—a friend who could help when the problems got too hard to

think through in advance. Such problems "would be easier to solve," he wrote, "and they could be solved faster, through an intuitively guided trial-and-error procedure in which the computer cooperated, turning up flaws in the reasoning or revealing unexpected turns in the solution."

Much easier said than done. Real-time computers were still a rarity in 1960, and far too expensive for individual use. Therefore, Lick concluded, the most efficient way to use this technology was to have the computer "divide its time among many users." This was not an original idea; such "time-sharing systems" were already under development at MIT and elsewhere. But Lick, never one to hold his imagination in check, followed that notion to its logical conclusion: He described an online "thinking center" that would "incorporate the functions of present-day libraries." He foresaw "a network of such centers, connected to one another by wide-band communications lines and to individual users by leased-wire services." Any similarity to today's Internet is not a coincidence. (To read Licklider's seminal paper, go to www.memex.org/licklider.html.)

Networks would allow computers to communicate with one another. But Lick also saw a desperate need for better ways for humans to interact with computers. Punch cards and printouts were, he wrote, hopelessly impoverished relative to human communication via sight, sound, touch and even body language. His proposed solution: a desk-sized console that would function much like today's personal computer, equipped with voice and handwriting recognition. He described a display surface "approaching the flexibility and convenience of the pencil and doodle pad or the chalk and blackboard."

Lick pointed out the need for reference works distributed via cheap, mass-produced "published memory" (think CD-ROM); data storage that could access items by content, and not just by names or keywords (still difficult); and languages that would allow you to instruct the computer by giving it goals, instead of step-by-step procedures (even more difficult.) He also revealed his mixed feelings about artificial intelligence, then in its infancy. He saw it as being potentially very useful—but knew far too much about the brain and its complexities to believe that computers would soon be surpassing humans.

Although Licklider's ideas were little more than visions in the late 1950s, technology was beginning to catch up. In the spring of 1960, a struggling young company called Digital Equipment Corp. introduced its first computer, the PDP-1. It was a real-time, interactive machine, and it came with a built-in display screen. It was the perfect machine for Lick to try to implement the research agenda laid out in "Symbiosis." He and his team bought the display model off the exhibit floor for $120,000 (enough to make the BBN higher-ups blanch) and plunged in. They programmed their PDP-1 for some of the first experiments with educational software, including a language vocabulary drill written by Lick himself. They experimented with online search and data retrieval. They even worked on time-sharing—although the PDP-1, whose horsepower was roughly that of the original Radio Shack TRS-80, didn't have much to share.

Building the ARPA Community

LICK WOULD HAVE HAPPILY CONTINUED THIS WAY INDEFINITELY, had he not received a call in 1962 from the Department of Defense's Advanced Research Projects Agency (ARPA). The Pentagon had formed ARPA five years earlier in the aftermath of Sputnik as a fast-response research agency, charged with making sure the United States was never again caught flat-footed. Now, ARPA wanted to set up a small research program in "command and control": the ancient art of making timely decisions and getting those decisions implemented by your forces in the field. This was a critical matter in the nuclear age, and was obviously going to involve computers. And once ARPA director Jack Ruina heard Lick expound upon his vision of interactive, symbiotic computing, he knew he had found the right person to lead the effort.

Lick didn't really want to leave BBN. But how could he say no? He would have $10 million a year to give away pretty much as he saw fit—no peer review, no second guessing from higher-ups. The ARPA style was to hire good people, then trust them to do their jobs. There would be no "cloak and dagger" stuff, as Lick called it; the research he funded would be completely unclassified. So long as he was advancing command and control, broadly defined, he could choose which projects to fund. In effect, Lick was being offered an opportunity to spend big money in pursuit of his vision of human-computer symbiosis.

He hit the ground running in October 1962. His strategy was to seek out the scattered groups of researchers around the country who already shared his dream, and nurture their work with ARPA funding. Within months, the "ARPA community," as it came to be known, was taking shape. First among equals was Project MAC at MIT, founded with Lick's encouragement as a large-scale experiment in time-sharing and as a prototype for the computer utility of the future. MAC—the name stood for both "Multi-Access Computer" and "Machine-Aided Cognition"—would also incorporate Marvin Minsky's Artificial Intelligence (AI) Laboratory. Other

Lick's kids: Licklider (right) made MIT's project MAC the computer-research epicenter.

LICKLIDER PHOTOS COURTESY OF THE MIT MUSEUM

major sites included Stanford, where Lick was funding a new AI group under time-sharing inventor John McCarthy; Berkeley, where he had commissioned another demonstration of time-sharing; Rand Corp., where he was supporting development of a "tablet" for free-hand communication with a computer; and Carnegie Tech (now Carnegie Mellon University), where he was funding Allen Newell, Herbert Simon and Alan Perlis to create a "center of excellence" for computer science. Lick had also taken a chance on a soft-spoken visionary he barely knew—Douglas Engelbart of SRI International—whose ideas on augmenting the human intellect with computers closely resembled his own and who had been thoroughly ignored by his colleagues. With funding from Lick, and eventually from NASA as well, Engelbart would go on to develop the mouse, hypertext, on-screen windows and many other features of modern software.

The trick, Lick knew, was to create a community in which widely dispersed researchers could build on one another's work instead of generating incompatible machines, languages and software. Lick broached this issue in an April 1963 memo to "Members and Affiliates of the Intergalactic Computer Network"—meaning his principal investigators. The solution was to make it extremely easy for people to work together by linking all of ARPA's time-sharing computers into a national system. He wrote:

> If such a network as I envisage nebulously could be brought into operation, we would have at least four large computers, perhaps six or eight small computers, and a great assortment of disc files and magnetic tape units—not to mention the remote consoles and teletype stations—all churning away.

From the modern perspective, this little paragraph is electrifying—it is perhaps the first written description of what we now call the Internet. But Lick didn't stop there. Clearly enamored by the idea, he spent most of the rest of the memo sketching out how people might use such a system. He described a network in which software could float free of individual machines. Programs and data would live not on an individual computer but on the Net—the essential notion of the Java applets now found all over the Web.

Lick couldn't do much about his idea immediately, since networking technology wasn't even close to being ready. So instead he talked (and talked, and talked), trying to sell the notion to anyone who would listen, confident that he was planting a seed that would grow.

Meanwhile, he had a program to run. Lick presided over his far-flung community in much the same way he'd run his research groups at MIT and BBN—with a mix of parental concern, irrepressible enthusiasm and visionary fervor.

True, his nonstop stream of ideas and suggestions could be exasperating; the recipients sometimes felt as though their sponsor's imagination was voyaging among the stars while they were still struggling to build a biplane. But Lick was more interested in being a mentor than a micromanager: As long as people made reasonable progress in the right direction, he would let them find their own way.

At ARPA, program managers traditionally moved on after a year or two to give someone else a chance, and Lick was no exception. But in September 1964, when he left ARPA for the IBM research laboratory, he took care to find a successor who shared his vision. His choice was Ivan Sutherland, a 26-year-old computer graphics genius from MIT's Lincoln Lab whose doctoral project, Sketchpad, was the ancestor of today's computer-aided design software.

Lick's influence would continue to be felt at ARPA for more than a decade. Sutherland's successor in 1966 would be Robert W. Taylor, who shared with Lick a background in psychology and who was probably Lick's most enthusiastic convert to the symbiosis vision. It was Taylor who would inaugurate the actual development of Lick's proposed computer network, which began operation in 1969 as the ARPAnet and ultimately evolved into the Internet. And it was Taylor who went on to head the computer group at Xerox's Palo Alto Research Center (PARC)—where, during the 1970s, researchers turned Lick's notion of symbiosis into a working system. PARC's radical developments included the first graphics-based personal

Stanford Unversity
John McCarthy (left) invents time-sharing and leads AI group; Ed Feigenbaum develops expert systems

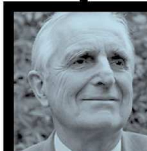
Keith Uncapher
Leads group at Rand Corp. that develops computer tablet interface

Carnegie Tech (Carnegie Mellon University)
Allen Newell, Herbert Simon, and Alan Perlis create a "center for excellence" for computer science

Marvin Minsky
Head of the AI Laboratory

MIT's Project MAC
Timesharing, networking, personal computing

Ivan Sutherland
Successor at ARPA and a pioneer in graphics



Douglas Engelbart
At SRI, develops the mouse and windows-style interface

Xerox PARC
Personal computers, object-oriented programming, laser printer

Robert Taylor
Starts ARPAnet project; organizes computer group at Xerox PARC

Larry Roberts
Designs and oversees ARPAnet, which evolves into the Internet

computer, the Ethernet local-area network and the laser printer. When Taylor left ARPA in 1969, he handed the reins to ARPAnet architect Larry Roberts, another computer graphics maven who had become intrigued with networking after a late-night bull session with Lick.

Lick always insisted, with characteristic modesty, that he had accomplished very little in his two years at ARPA. In a narrow sense, he had a point. Essentially nothing was happening in September 1964 that had not already been underway in one form or another when he arrived at the agency.

And yet, Licklider's impact was profound. When ARPA presented him with a never-to-be-repeated opportunity to turn his vision into reality, he had the guts to go for it. Once he had the Pentagon's money in hand, Lick had the taste and judgment to recognize good ideas and good people. He had the competence and integrity required to win their respect. And he had the overarching concept—human-computer symbiosis—that let each of his disciples feel like a part of something much larger than themselves. Most important, by funneling so much money into research at universities, where most of it actually went to support students, he guaranteed that his vision would live on after him.

"It seems to me that Licklider and ARPA were mainly about winning the hearts and minds of a generation of young scientists, and convincing them that computer science was an exciting thing to do," says James Morris, chair of the Carnegie Mellon computer science department. "In the aftermath of Sputnik, the glamour field was physics, not computing. Lots of very smart people made a career decision to go into a field that didn't exist yet, simply because ARPA was pouring money into it."

"Lick" presided over the computer research community with visionary fervor—and $10 million a year in Pentagon funds.

Forgotten Revolutionary

AS ELOQUENT TESTIMONY TO THE SUCCESS OF LICK'S STRATEGY, consider that during the late 1960s and early 1970s, at the height of the Vietnam debacle, when many people viewed governments and institutions of all kinds as instruments of oppression and punch-card belching mainframes as a potent symbol of tyranny, a rising generation of students was beginning to think of computers as liberating. This was the generation that would gather at Xerox PARC. And this was the generation—together with the students they taught—who would engineer the personal computer revolution of the 1980s and turn the ARPAnet into the Internet and then create the World Wide Web. The list is a long one, including Alan Kay of the University of Utah, who in 1968 came up with the notion of a notebook computer called the "Dynabook"; Dan Bricklin of Project MAC, who invented VisiCalc, the first electronic spreadsheet; Bob Metcalfe of Project MAC, inventor of Ethernet and founder of 3Com; John Warnock of Utah and PARC, founder of Adobe Systems; and Bill Joy of Berkeley, co-founder of Sun Microsystems. Even now, people who never heard of J.C.R. Licklider fervently believe in what he dreamed of, because his ideas are in the very air they breathe.

Why, then, have most people never heard of him?

One reason is that Lick wasn't the kind of person modern-day computer journalists like to write about. He didn't start a company, or create best-selling software. He wasn't a mediagenic guru. He seemed to be just another government bureaucrat from back in technology prehistory. Moreover, Lick wasn't even very successful as a bureaucrat, at least not after he left ARPA. Two exasperating years at IBM sent him back to MIT in 1966; the computer giant's corporate culture was grounded so firmly in mainframes and batch-processing that Lick saw no chance to convert the company to human-machine symbiosis in his lifetime. His rocky stint as director of Project MAC, from 1968 to 1971, strained many an old friendship there; Lick's loathing for paperwork made him a disastrous manager. A second tour at ARPA, from 1974 to 1975, was even worse: In the post-Vietnam environment, the free-wheeling computer research program he had founded was mired in demands for immediate military relevance. A colleague who watched him there likened it to a Christian being fed to the lions.

And Lick wasn't a young Christian anymore. By the time microcomputers hit big in the early 1980s, he was pushing 70. Just as his ideas of personal computing and networking were coming to fruition, he was losing the vigor to contribute significantly to the cause. His hands had a noticeable tremor—a condition that would eventually be diagnosed as Parkinson's disease. His allergies had crossed the line into asthma, and he never went anywhere without an inhaler. In the end, it was the asthma that finally caught up with him: An attack left his brain without oxygen too long, and Lick died without regaining consciousness in June of 1990.

But mainly, we haven't heard of Lick because he refused to toot his own horn. He seems to have been one of those rare beings who genuinely didn't care who got the credit, so long as the goal was accomplished. Psychologist George Miller, who worked with Licklider at Harvard during World War II, remembers him as "extremely intelligent, intensely creative, and hopelessly generous" with his ideas.

Forty years later, Stuart Malone discovered much the same quality. In the early 1980s, Lick had taken Malone and a number of other undergraduates under his wing. He made sure they had a space of their own, a common area they painted green and called "The Meadow." He got them exclusive use of one of the lab's VAX/750 computers, which they immediately equipped with a Unix password: lixkids. He had made them feel part of something much larger than themselves. And, of course, he had said not a word about his own past—which was why Malone was so astonished at Lick's retirement dinner in 1985. "There were hundreds of people there from MIT, from DEC, from PARC, from the Defense Department," he recalls, "all standing up and crediting Lick with giving them a chance to do their best work."

David Burmaster, who had been Lick's assistant at Project MAC, will never forget it. "I'd felt I was the only one, that somehow Lick and I had this mystical bond. Yet during that evening I saw that Lick had had this amazing relationship with—a hundred? Two hundred? I'm not sure even how to count them. And everybody he touched felt that he was their hero, and that he had been an extraordinarily important person in their life." ◊

California Dreamin' Sony Style

Leading Japan's best-known consumer electronics company into the new world of "convergence" is a very small, very un-Japanese research lab based on an illustrious model: Xerox PARC.

BY BOB JOHNSTONE

PHOTOS BY TOM WAGNER/SABA

INCORPORATED IN AIBO, THE CUTE, SILVER-toned pet robot dog that went on sale June 1, was much that resonated with the history of its maker, Japan's Sony Corporation.

For instance, the novel coupling of "entertainment" and "robot" recalled the pairing of "personal" and "stereo" in the Sony Walkman two decades earlier.

There was the "Memory Stick" lodged under Aibo's tail, a new data storage medium about the size of a piece of chewing gum that could someday become as ubiquitous as that other Sony invention, the 3.5" floppy disk.

And Aibo's rechargeable lithium-ion batteries were yet another Sony original, developed in this $50 billion giant's seemingly never-ending quest for smaller, faster, friendlier consumer electronics products.

Those innovations fit neatly into Sony's track record. But Aibo had at least two unfamiliar aspects. One was the way Sony chose to make the new home-entertainment robot available: only over the Internet, where all 3,000 units of the Japanese allocation were snapped up in *17 seconds*. The other was

Aperios, its operating system.

Wait a second…an *operating system* from Sony? What gives?

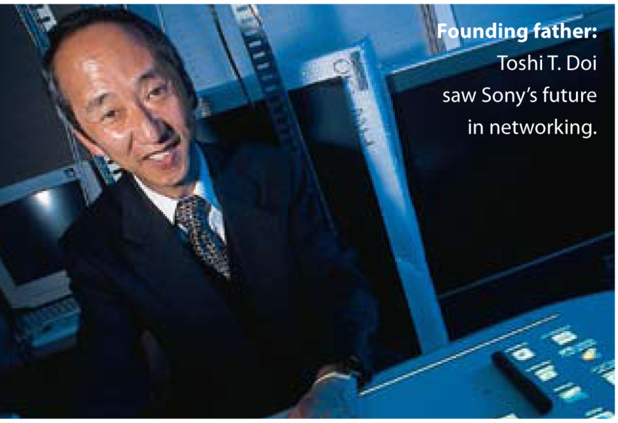
The digital revolution. Just before the final Christmas shopping season of the millennium, the world's best-known electronic consumer goods maker has decided to re-invent itself for the Internet age. The transformation is being led by Nobuyuki Idei, the tough-minded president who took Sony's reins in 1995 and took to the digital agenda in a big way. The new motto he gave the company, "Digital Dream Kids," is also an excellent description of Idei's unusual brain trust—the Sony Computer Science Laboratory (CSL).

Founded a decade ago, CSL is a very un-Japanese research shop set up in emulation of the mother of all computer science labs, Xerox's Palo Alto Research Center (PARC). At CSL's Tokyo offices, thirty-odd researchers now work on deep concepts of computer connectedness and far-out interfaces. What's more, they've been tapped by Idei to help lead him and the rest of Sony's 170,000 workers into the new world of "convergence"—where the PC and home audiovisual appliances merge, and Sony battles Microsoft.

In fact, that battle has already begun. The Aperios OS, invented at CSL, and Microsoft's Windows CE are squaring off in a struggle for preeminence inside the TV set-top box, the latest portal for digital cable services and a possible linchpin for the high-speed "home network" that Idei's company hopes will ultimately link each of its products not just to one another, but also to the Internet.

Not Sony's Way

SINCE THE COMPANY'S FOUNDING IN 1946, Sony has largely been driven by physicists and materials specialists whose style of innovation was to take key enabling devices and turn them into new and useful consumer products. A classic example of Sony's eye for hardware's "killer app" is the transistor, which Sony turned into its first hit product, pocket-sized radios. And it was Sony (after spending 13 years and $200 million) that first transformed the charge-coupled device (CCD) into a marketplace success—in the form of its best-selling camcorders.



Founding father: Toshi T. Doi saw Sony's future in networking.

Although wildly successful, Sony's pattern of innovation did not extend to computers. Sony management had never put much effort into computer R&D, believing the company's core business would always be manufacturing groovy audiovisual equipment. The strategy posed a stark danger: that Sony would become irrelevant in the emerging digital world.

That danger was particularly clear to Toshi T. Doi, an expert in digital audio who had played a key role in the development of the compact disc player. Doi arrived at Sony's computer business group in May 1984, just in time to witness the launch of Hit Bit, a home PC that he wryly describes as "the last eight-bit machine in the world." Other failures followed, but undaunted by Sony's computer allergy, Doi and a group of 11 engineers proposed developing a serious, low-priced engineering workstation called NEWS. "It was our last card," Doi recalls. "If it had failed, that would have been all for Sony" in the computer area. Launched in January 1987, NEWS was a big hit in Japan, quickly taking top share in the local market (though it tanked in the United States, bested by superior products from the likes of Sun Microsystems).

Though NEWS was successful, Doi was dissatisfied. "When I opened the box," he recalls, "it was nothing but assembly—we were buying CPUs from Motorola, licensing Unix from UC Berkeley. There wasn't any Sony original technology included, and I thought, 'This is not Sony's way.'" Where, wondered Doi, was the innovative technology core that could drive new products and markets, just as the transistor and the CCD had?

Working with Unix had alerted Doi to the importance of the Internet, and he foresaw that in the 21st century, networks would connect billions of computers. In April 1987, Doi asked his management to let him establish a software lab to focus on network design. NEWS' success made Sony management receptive to Doi's proposal. He got funding and a new mandate: Think long range.

Sony's **pattern** of innovation **posed** a stark **danger**—that the **company** would become **irrelevant** in the **digital** world.

As he began putting his group together, Doi had PARC very much in mind. During the 1970s, PARC was a place where researchers enjoyed unique freedoms. It had proved an excellent research strategy. From PARC came the graphical user interface, the laser printer and the Ethernet. To get his project up and running, Doi asked his friend and fellow amateur jazz musician, former PARC luminary Alan Kay, for guidance. At the same time, Doi approached Mario Tokoro, a Keio University professor known for his strong technical background in operating systems and networking, as well as for his visionary streak.

Tokoro remembers that Doi's timing was perfect. "At that time, as a professor, I was a little frustrated," Tokoro says. "The PhD students I produced were not given a chance to fully exhibit their performance even in the research labs of top-level Japanese firms. Bureaucracy and strict seniority systems were so strong. Originality was not considered important. And I was thinking whether I should start something." The pair saw eye to eye—networks were the future, and intellectual freedom could make Sony a player. Doi offered Tokoro the job of lab director.

Freedom Breeds Content

THESE DAYS, A GOOD PLACE TO MEET Tokoro is in the massive self-service cafe-

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SONY

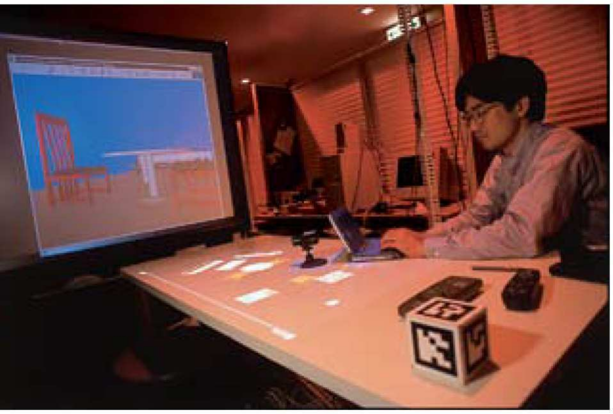
teria at Sony's Tokyo headquarters in Shinagawa, where he lunches most days with colleagues from CSL. Tucked inside the southern tip of the Yamanote, the loop line that defines central Tokyo, Shinagawa could these days justifiably be renamed Sony Town. The company owns at least a dozen high-rise buildings in the area, and its logo is everywhere. The CSL is located in an eight-story tile and glass edifice hidden on a side street, out of sight of Sony's headquarters complex, but no more than a five-minute walk from president Idei's office.

CSL's director is short, pudgy and dressed in a standard-issue salaryman suit; a casual encounter yields few clues about what lies behind the conventional facade. A better insight can be found on his Keio University Web page, where one of his students mischievously posted a cartoon of him clutching a Nintendo-like magic mushroom. The implication is obvious: shy, mild-mannered Professor Tokoro is actually…Super Mario!

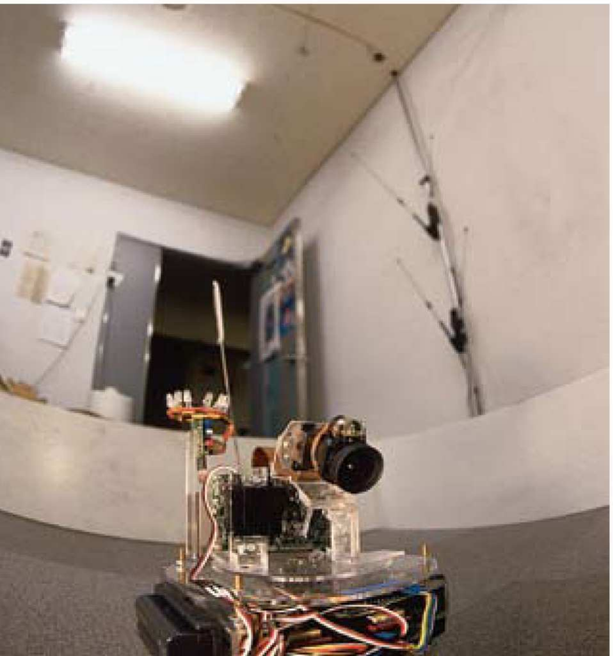
In Japan, where universities tend to be ivory towers and academics are suspicious of industry, it is extremely rare for professors to join companies. Indeed, Tokoro made a lengthy transition. For the first 10 years of the CSL's existence, he kept his position at Keio and worked for Sony part-time. In March 1997, he joined Sony as a full-time employee. Two years later, Tokoro was promoted to senior vice president making him, at age 52, Sony's most senior corporate research executive. "That's a very strange place for an academic," comments Dave Farber, a University of Pennsylvania computer science professor who has known Tokoro for many years. "There's a president [Nobuyuki Idei] and two people under him, and Mario's one of them. And if you look at Sony, the new president has essentially said, 'The IT area's our future.' So that puts Mario in charge of one of Sony's most important commodities."

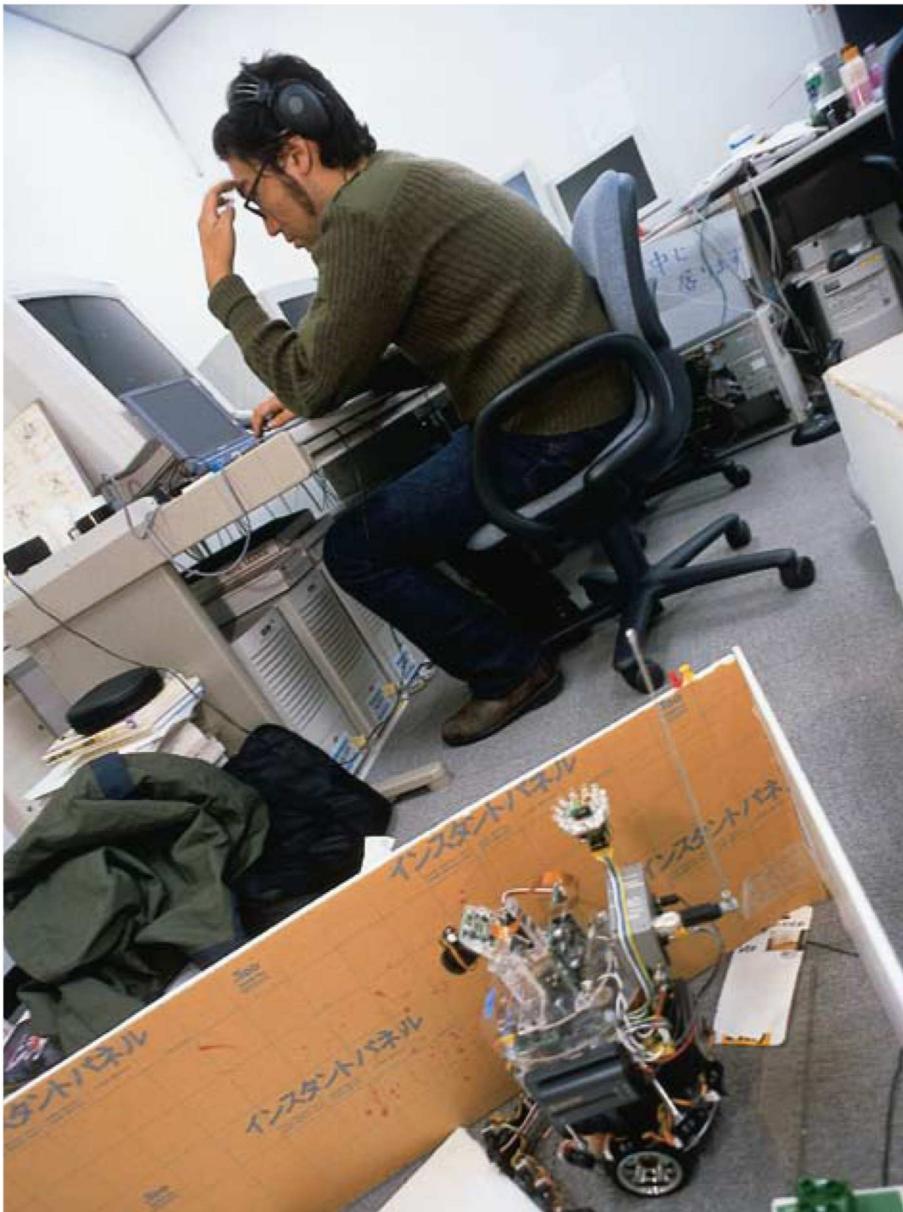
Inside the CSL, the atmosphere is casual and relaxed. Researchers wear polo shirts, jeans and sandals. A sticker on one door reads "MIT Nerd Pride." The lab is decorated in muted colors, with central meeting areas furnished with soft black sofas. Spacious individual offices take advantage of the light from surrounding windows. There is no obvious center of power, no signs indicating titles or seniority. It is, in short, completely unlike most Japanese industrial labs.

"Much of CSL's uniqueness comes simply from the fact that it's essentially a very Western lab," says Rodger Lea, a 36-year-old Englishman who worked there from 1994 to 1997, and now runs a Sony software development lab in Silicon Valley. "Japan is such an immensely conservative, hierarchical bureaucracy, whereas CSL is a meritocracy, people are



Sony think tank: Jun Rekimoto uses tabletop projections to extend the computer interface (above). An assistant in Jun Tani's cognitive robotics lab studies adaptive behavior using a navigational robot (right, below).





successful based on their ability to perform." Unlike the rest of Sony, CSL employs researchers on a one-year contract basis, with annual performance reviews. Salaries are high, but they are based on success, not on seniority.

Not surprisingly, there's no shortage of applicants hoping to join Sony's digital dream team. CSL has attracted some of Japan's most promising computer whizzes—including some from other companies. Until recently, job-hopping was a rarity in Japan, but CSL's offices are filled with renegades from the likes of Canon and NEC. All must meet Tokoro's definition of a good hire: "Originality and vision; the strong will to deny orthodoxy and to challenge the future."

To promote the creativity that produces good software, Tokoro adopts a Western, hands-off style. "His policy is that the best management is not to try and manage," explains Hiroaki Kitano, one of CSL's most productive researchers *(see "Sony Supernova," this page)*. "All he does is hire the best researchers and let them do what they want. In five years, he has never told me what I'm supposed to do. He always says, 'Do whatever you want, and the only thing is to be the best and have results with the highest impact.'"

Network of the Future

DESPITE CSL'S FREEDOMS, TOKORO IS WELL aware of the pitfalls in the PARC model. After all, Xerox failed to capitalize on almost every one of the new technologies that poured forth from the Palo Alto lab. CSL's aim isn't just exciting technology, says Tokoro: "The ultimate and unchangeable goal of CSL is to develop technologies that create new markets for Sony."

Tokoro sees Sony's future in the emerging ubiquitous network of computers on desktops and in consumer devices. This network, he says, must be regarded as a continually evolving "open system," a view that is reflected in CSL's strong emphasis on widely distributed, mobile computing environments where network connections, connected computers and services are changing continuously.

For instance, CSL researcher Fumio Teraoka has been working with NTT and Keio University to solve key problems related to next-generation, broadband Internet use by consumers. "In the future, we believe each household will be con-

Idea explosion: Hiroaki Kitano is one of Sony's new breed of software innovators.

Sony Supernova

The story is told of Hiroaki Kitano at a molecular biology symposium in Japan last year where the eminent guests included Nobel laureate Sydney Brenner. When the time came for the commemorative photograph, Kitano, then all of 37 years old, took a seat in the front row. In Japan, where age and status are venerated, Kitano's move to center stage was seen as an act of shocking presumption. But it wasn't at all out of character for Sony Computer Science Laboratory's (CSL) brightest star.

Call him big-headed if you will, but since joining CSL in 1993 Kitano has made his supernova-like presence felt in areas as diverse as e-commerce, robotics and biology. Corroborating evidence for the breadth of Kitano's activities comes from the extraordinary explosion of books and papers that make access to his office at CSL well-nigh impossible. Kitano says there's a method behind the clutter—he dumps everything on the floor in chronological order.

Kitano got his start in computing at Tokyo's International Christian University when he left particle physics to major in artificial intelligence (AI). The field struck Kitano as "very wild—you can do anything you want, you can actually make a difference." Before landing at CSL, he spent a decade working at NEC and later at Carnegie-Mellon University on speech recognition.

Kitano is best known for the Robot World Cup Initiative, a soccer competition for wheeled robots he started in 1993. RoboCup's ultimate goal is to field a team of androids by the mid-21st century that can defeat the best human team. Meanwhile, the annual championships have become an immensely popular test-bed for new ideas in AI and robotics research. This year, in Melbourne, 100 university teams from 35 countries will participate in RoboCup 2000. And for Sony, one of the competition's major sponsors, there are payoffs in the shape of new technologies for the company's entertainment robots. Some of the ideas RoboCup generated have ended up inside Aibo, Sony's $2,500 robot dog. "If you look at the future of computing," Kitano predicts, "the major area of work will be entertainment."

But recently, Kitano became frustrated with AI research. "I felt that we were just scratching the surface," he says. To build better robots and more useful computers, he believes that "we need to have some very fundamental understanding of what life and intelligence is all about." So with CSL's blessing, Kitano has begun digging into molecular biology and neuroscience. In one project with collaborators at the California Institute of Technology, he is building computer models to understand how genes interact. "Biologists haven't been able to deal with complexity," says Caltech biology division chair Mel Simon, "We haven't got the systems or levels of abstraction, and this is what engineers can bring us. And I think Kitano sees that very, very clearly."

Thanks to his impact and imagination, Kitano isn't the only one who thinks he belongs in the front row these days. "Sometimes I get a call from [Sony president Nobuyuki] Idei to come by his office and give him my thoughts," admits Kitano, who describes his advisory role as "sort of like a CIA agent—my position never shows up in any official records."

Face time: Kim Binsted's HyperMask projects animations onto an actor's mask.

The Technology of Fun

It's the middle of a hot, humid June Friday on the third floor of Sony's Computer Science Laboratory (CSL). Associate researcher Kim Binsted is tired, having overslept after her regular Thursday night improv at the Tokyo Comedy Store. It is, she says, "a bad habit" of which her boss, CSL director Mario Tokoro, "completely approves. Every time he shows people around he's like, 'This is Kim, she's a comedian'."

Indeed, this 26-year-old's comedic credentials are impeccable. She earned her PhD from the University of Edinburgh for developing JAPE (Joke Analysis and Production Engine), the world's first punning software, and has participated in panel discussions on humor and artificial intelligence with the likes of Steve Martin and Marvin Minsky. Part hacker, part theater department ham, Binsted's take on the technology of fun is dead serious. "I think the corporate world could do with some basic research on entertainment," she says. "Not just 'Oh, how do we make our graphics go faster?' But looking at entertainment itself, how does it work, what are the markers of an entertaining experience, and how can computers make things in general more interesting?"

One of two non-Japanese researchers currently at CSL (she's a dual U.S.-Canadian citizen) and the lab's only female, Binsted works in CSL's Interaction Laboratory, a research group headed by Jun Rekimoto where work on novel computer interfaces emphasizes augmenting the real world with digital information. For instance, she is collaborating on a project called HyperMask, demonstrated at Siggraph in Los Angeles in August. In the demo, Binsted, dressed as a chambermaid, moved around the stage, wearing a white mask. As she did so, a projecter tracked her movement and flashed animated computer-generated images onto the mask, matching the stories she was acting out. And as she spoke, the lips of the projected face moved in synchrony with her voice. "It's quite fun wearing somebody else's face," says Binsted, who thinks HyperMask's new style of storytelling holds promise not just in theatre, but also in karaoke clubs (she suggests putting on Elvis' face while singing, say, Jailhouse Rock), theme parks and even as an educational aid in classrooms.

Binsted's bet for a next big trend is emotionally responsive computer gaming: "If you could actually have some direct feedback, say the emotions of the player being tracked by the joystick, the game could be like a performer on stage, able to adjust the performance according to the actual reaction of the audience." Imagine, says Binsted, an interactive movie or game where the "boogeyman jumps out from behind the door to get the maximum startled effect from the user!" Wild stuff, but so far Binsted says she hasn't been able to capture the attention of developers at Sony Computer Entertainment, the division that produces the hugely popular PlayStation game console. "They're not interested in what we're doing here," she laments. But as CSL takes on an important role leading Sony into the 21st century, their interest might just grow.

nected by a very fast line to a backbone," explains Teraoka. "We want to send content to the home, but the current Internet cannot guarantee the quality of service." Although today's geeky early adopters may be willing to sit through countless delays just for the fun of downloading video off the Internet, tomorrow's wired couch potatoes will demand smooth, real-time transmission. The solution Teraoka's group came up with, "Media Cruising," has two components. One enables users to reserve in advance the bandwidth needed to transmit a particular chunk of content. The other is a new protocol for efficiently transporting bulk data. Last February the technologies were transferred to a corporate development group, which is now working on a commercial-strength version of Media Cruising.

Tokoro believes there's another crucial area of opportunity for Sony in computing: the human interface. As computers multiply and become smaller, starting with cell phones and personal digital assistants, the GUI, or graphical user interface, perhaps PARC's most important legacy, is looking clunkier and clunkier. Tokoro's idea: "We have to envisage humans as open systems in order to develop intimate user interfaces. "

CSL's Jun Rekimoto shows the idea in action with a special pen he's developed for moving data between computers. Pointing it at one machine, then another, a file jumps between the screens. In fact, the data is transferred via a wireless network, and the pen is simply a command device. But the user has the illusion that the data is in the pen, and that the desktop's drag-and-drop metaphor has magically entered three-dimensional space. Easy manipulation of digital objects, says Rekimoto, is "the first step for a ubiquitous computing environment." Tokoro believes designing better interfaces means learning "more about humans," which is why at CSL, researchers can be found studying human traits such as intelligence, even humor.

Convergence Wars

WITH JUST 32 RESEARCHERS IN ALL (including four at a branch lab in Paris that specializes in human cognition), the CSL is a tiny outfit. Nonetheless, CSL's vision, products and graduates are playing a key role in Sony's digital transformation.

"The CSL is like a pipe," according to Doi, who is now the lab's chairman. He counts four laboratories now headed by CSL members or alumni, including his own Digital Creatures Laboratories, which produced the robot dog Aibo. "Today," Doi laughs, "Sony research is occupied by CSL graduates!"

Unlike the situation at PARC, a steady stream of CSL ideas are now making themselves felt where it counts—in the market. One example: Sony's ultra-slim VAIO notebook computer is a huge hit in Japan in part because of NaviCam, a key differentiating concept developed at CSL in 1997 by Rekimoto. NaviCam, a tiny built-in digital CCD camera above the notebook's screen, captures video images that can be edited and transmitted as e-mail over the Internet. NaviCam grew out of Rekimoto's idea for an advanced type of human-computer interaction in which computers would be aware of people; in development, the concept was transformed into "personal video," a blend of AV and IT technologies that satisfied Sony's desire "to promote the computer for more entertainment-oriented uses."

Perhaps the best example of CSL's impact on its parent is the lab's oldest project, the Aperios operating system. After an incubation of six years, Aperios was transferred out of CSL in 1996, together with four or five of its developers, including group leader Akikazu Takeuchi, a 45-year-old former Mitsubishi Electric researcher. Takeuchi now heads a corporate software lab called the Sony Suprastructure Center responsible for home networking and operating system development.

Aperios is a "real-time, object-oriented OS with a reflexive architecture"—a mouthful that means it is particularly good at handling high-speed video and audio streams. It's this ability that lets Aibo track and intercept the bright pink ball it's sold with, and also what's led Sony to place Aperios at the vanguard of the strategy to conquer the home network.

Sony has begun pushing Aperios as the OS for a new generation of TV set-top boxes that are allowing cable companies to deliver hundreds of new channels, as well as interactive services such as Internet access, video-on-demand and games. In May, Sony began selling a set-top box called Plus Media Station in Japan; in October it announced plans to supply New York's Cablevision Systems with set-tops for its rollout of digital cable to 3.5 million subscribers in and around New York, Boston and Cleveland.

What turns the set-top into the hub of a home network is i.Link, Sony's version of Apple's FireWire high-bandwidth interface. The i.Link connection can transmit data at a speedy 400 megabits per second, and Sony already includes it on some camcorders and the VAIO notebook. Last May, Sony teamed with seven other consumer electronics companies, including Philips, in announcing a standard specification—known as home audio-visual interoperability, or HAVi—that should let these companies' products all talk via i.Link. For consumers, the bottom line on Aperios/HAVi/i.Link is better entertainment: You'll be able to download the latest Mariah Carey single from the Web via your TV set-top box, route it to your digital video disk player, and be boogeying in no time.

CSL is intent on seeing its innovations become products for its parent company unlike its inspiration: Xerox PARC.

Of course, Bill Gates has his own plans for your living room. Not only is Microsoft promoting Windows CE as an alternative OS for set-tops, but along with Intel, the Redmond empire is pushing its Windows-centric alternative to HAVi called Home API, which can control a home's lights, thermostat and stereo—from the safety of the PC.

The convergence war isn't quite as simple as TVs versus PCs, however, since Sony's vision for your living room doesn't necessarily rely on a set-top box. "What's going to be interesting is home networks where devices are capable of advertising their presence and their capabilities and working together cooperatively," says Rodger Lea, the CSL grad who directs Sony's Distributed Systems Laboratory in San Jose, Calif., a 70-person outpost of the Suprastructure Center that monitors U.S. developments and supports Sony's U.S. product groups. "One of the key things we've tried to achieve with HAVi is that [like the Internet] it's very distributed—we don't want to rely on a single device to be the controller in the home: Any device can be the controller. This is very important for a consumer electronics company which sells a range of appliances. It's obviously less important for a PC company, which has a very PC-centric view of the world."

But the situation is evolving almost daily. In the latest twist, Sony and Microsoft have actually joined hands, along with a score of other firms, to advance yet another standard—Universal Plug and Play—based on the protocols that govern the Internet. "What you're looking at is convergence. What used to be separate turfs are becoming a single market, and there is a huge struggle for who will dominate," says MIT computer science professor Carl Hewitt, who once taught alongside Tokoro at Keio University and spent time at CSL. "Bar none, the biggest challenge for the CSL is to lead Sony through this paradigm shift."

It's a challenge Tokoro is looking toward with confidence. In the future, says Tokoro, "Sony will not only be a leading-edge consumer electronics manufacturer, but also a company which provides network service infrastructure as well as services on the network." And not just any networked-consumer electronics company, he asserts—the market leader. And his vision for CSL is no less bold. He wants his un-Japanese organization to become the "world's number one" place for doing computer science research. The next few years will tell whether he's succeeded, and whether his California-style transplant can lead Sony into the age of the Internet. ◊

Idea architect: Former professor Mario Tokoro leads Sony's IT strategy.

Ray Kurzweil created a hubbub with his idea that we will soon be able to "download" ourselves into machines and live forever. Find out what else he's got up his futuristic sleeve.

The Story *of the* 21st Century

Q & A

Struggling to find time in a busy schedule for yet another interview, Ray Kurzweil jokes that the media frenzy surrounding him these days only happens "every thousand years." That's because the inventor and entrepreneur who brought us such products as the Kurzweil electronic keyboard, a text-to-speech reading machine for the blind and voice-recognition software is also of the most audacious—and, some say, accurate—futurists around. Kurzweil's fearlessly detailed predictions make his latest book, *The Age of Spiritual Machines*, a must-read for the turn of the millennium.

TR Associate Editor Rebecca Zacks visited Kurzweil at the Wellesley Hills, Mass., offices of Kurzweil Technologies, one of the half-dozen high-tech companies he has founded since selling his first major enterprise to Xerox in 1980. The son of a composer and trained as an MIT undergraduate in both computer science and creative writing, Kurzweil moves deftly from music and art to computer processors and nanotechnology to immortality, evolution and God. And though his manner and his gray pinstriped suit are remarkably subdued, his ideas about the future are explosive.

TR: You're accomplished both as an inventor and as a writer—how do you see those two roles fitting together?

KURZWEIL: In writing, you're also inventing. My main interest is to write about the future, though I did write a health book. Lately, my interest in health has intersected with my interest in computers, because they both have a bearing on the issues of longevity and immortality—keeping our biological bodies and brains healthy is the first bridge to immortality. That'll bring us to the bioengineering revolution. Within 10 years, bioengineering will extend human life spans at least a year every year. And that'll be the second bridge that'll bring us to the nanotechnology artificial intelligence revolution, which gives us a real shot at immortality. But writing about the future and technology is also an invention process, because you have to invent the future to have a compelling statement about it.

TR: One of your more dramatic statements is that in the second half of the 21st century we'll routinely be able to scan a person's brain and "reinstantiate" that person in a computer—no more squishy human body necessary. What did you have to mentally invent to come up with that scenario?

KURZWEIL: People ask, "How is that possible, scanners really can't resolve to that resolution," so I came up with the idea of scanners that would scan the brain from inside. We already have scanners that can scan with extremely high resolution, providing the scanning tip is right next to the neural features. Well, how are you going to move the scanning tip to every point in the

PHOTOGRAPHS BY DAVID ZADIG

brain without destroying the brain? The answer is to send them in as nanobots, blood-cell-sized robots with little scanners that would travel through every capillary in the brain. How would they communicate with each other? They would all be on a wireless local area network, and they would use distributed processing, thus the computational ability of the nanobots would be assembled into one distributed parallel computer.

TR: Is this something we could do today?
KURZWEIL: Every aspect of it is feasible today, except for the size and the cost. And that's where what I call the "Law of Accelerating Returns" comes in: There are all these accelerating technological processes that are increasing exponentially the cost effectiveness of computing. So the requisite computing for this scenario will be quite feasible within 25 to 30 years. What about size? Well, miniaturization is another exponential trend in technology, and right now we're shrinking the size of technology by a factor of 5.6 per linear dimension per decade, so again, you can predict that this will be feasible within 30 years.

TR: What mistakes do technology forecasters commonly make?
KURZWEIL: A lot of people when they talk about the future do it without any foundation or methodology. They, for one thing, are very afraid to look beyond one or two iterations of technology—for example that screens will be higher resolution, a little smaller, but then progress will stop. People very often fail to see the interaction between many different trends. If you look in different fields—brain scanning, nanotechnology, artificial intelligence, computing substrates, communication—you see how all of these fields are going to interact with each other to provide tools that in turn accelerate progress in each other. The most important element that's very commonly missed, even by sophisticated futurists, is the accelerating pace of change. A futurist may make a statement that we won't see a particular development for 30 years, because a comparable change took 30 years in the past. But time and the pace of progress is accelerating, so something that took 30 years in the past will only take 7 years in the future.
TR: How do you quantify the future pace of technological progress so precisely?
KURZWEIL: Over the past 20 years, I've developed a mathematical model for what will be feasible in terms of computational power and memory and miniaturization, so that I have some methodology for making these predictions. The predictions that I made in the '80s about the '90s were quite accurate. I predicted, for example, that the computer would take the world chess championship in 1998—I was off by a year.

TR: Is the accelerating development of technology, in particular computer technology, inevitable?
KURZWEIL: The creation of more and more intelligent machines is an economic imperative. People sometimes say maybe we'll get to a point where we'll decide not to build these machines because they'll be too threatening, but it's not a realistic scenario—we'd have to repeal economic competition, free enterprise, capitalism, to stop that progression. Anytime anyone creates a machine that's a little bit more intelligent, it takes over the market. There are tens of thousands of projects with the force of economic competition driving the whole process forward. It's not a centralized decision.

TR: How will we get from faster and smaller computers to computers with human intelligence?
KURZWEIL: Basic computational power is a necessary but not sufficient condition. There are a number of different scenarios for how we can organize the software of intelligence, but the most compelling one is that we have an example of an intelligent entity in our midst: It's the human brain and it's not hidden from us. We're already down the path of learning about it. For example, we use the kinds of transformations the human brain does on auditory information in our speech recognition system. There's going to be a tremendous incentive to learn about the brain, to learn the secrets of intelligence and then replicate those methods. If you ignore this resource of the human brain, then you might say that we'll never figure out the software of intelligence.

TR: Part of your mathematical methodology dictates that evolutionary processes expand exponentially, and that the development of technology is itself an evolutionary process—can you explain?
KURZWEIL: Think about the evolution of life on earth. It took billions of years for the first cells to form, and then in the Cambrian explosion, paradigm shifts only took a few tens of millions of years. Then later on, we went from primates to humanoids in only millions of years, and then *Homo sapiens* emerged in only hundreds of thousands of years. And then it became too fast for DNA-guided protein synthesis to keep up the pace of progress, so the whole cutting edge of evolution on earth has moved to technology created by the technology-creating species. So in my view, technology is actually a continuation of the evolutionary process that gave rise to the technology-creating species in the first place.

We can describe evolution as a sort of

essential spiritual quest. As we evolve, as matter and energy evolves, it creates entities that are more intelligent, more creative, more beautiful, more loving. These are all the qualities that we associate with God. God has been called infinite—infinite knowledge, infinite intelligence, infinite creativity. Evolution never really becomes infinite. It remains finite, but it does become very large, so it's moving in that kind of spiritual direction.

TR: We're asymptotically approaching God?

KURZWEIL: But never reaching it. By the end of the 21st century, nonbiological intelligence will be trillions of trillions of times more powerful than human intelligence. That's hard for us to imagine, and maybe from the human perspective, it's virtually infinite. But from a literal mathematical perspective, it's still finite, so we can consider God as an ideal that evolution never reaches.

TR: It sounds like such an optimistic vision. Are there no drawbacks?

KURZWEIL: I think there's always a struggle between the constructive and the destructive forces of technology. Biotechnology today is a very good example: On the one hand, we're at the very early stages of a burgeoning revolution that's going to reverse disease and aging processes over the next five to 15 years. But there's an obvious downside: The means and skills exist in a routine bioengineering laboratory to create a pathogen that would be more destructive than an atomic weapon. The technology we're creating for the 21st century will be even more powerful. Because it's self-replicating, nanotechnology will ultimately be able to provide anything in the physical world that we want, so if properly applied, it can meet all of our needs and desires and create fantastic wealth. But there are also enormous dangers to nanotechnology. Self-replication run amok would be a nonbiological cancer that would be even more destructive than a biological cancer.

I tend to come out on the optimistic side of the field, that overall technology creates a better world despite our sometimes feeling a romantic desire for the good old days. Richard Dawkins calls evolution "the blind watchmaker"—I think he should have called it the "mindless watchmaker," because he was using "blind" to mean "mindless," which is insulting to blind people. There's no intelligence behind the process but yet nonetheless it created all the wonders of the natural world and created human beings. This next stage of evolution, which is technology, is a mind*ful* watchmaker. So we do have actually the ability to guide that process, and therefore the responsibility to guide it in constructive directions.

TR: One area where your companies and inventions have already played a role in guiding technological evolution is in the arts, and your most recent piece of software, "Ray Kurzweil's Cybernetic Poet," is a foray into electronic writing. How does it work?

KURZWEIL: It's a system that reads poems from a particular author, and it creates a language model that describes how those poets create poetry, and then it can write original poetry in that style. Probably the majority of those poems don't work fully. However it comes out with really terrific turns of phrase and very interesting lines of poetry, so we've packaged it as a poet's assistant—you write a poem in one window and the Poet's Assistant will give you ideas for alliterations, rhymes, half rhymes, the next word of your poem, and turns of phrase that are relevant to what you've written, and you can fill up the screen with these different suggestions. It doesn't have human intelligence but it can do clever things with language, and help you to write a poem of even prose. It's available as a free download at www.KurzweilCyberArt.com.

TR: What will happen as computers become more artistically adept, and something like a cybernetic poet does reliably write poems that work?

KURZWEIL: In order for a computer to create completely satisfactory art, it needs to have a human level of intelligence. And when a computer does have a human level of intelligence, it brings up the issue of who is human—some of these cybernetic poets and artists will think that they are. And once a machine achieves a human level of intelligence, it will necessarily soar past it, because machines already have certain advantages over human intelligence. One is the ability to share their knowledge by quickly downloading software. They inherently will be much faster than humans because their electronic circuits are already 10 million times faster and their memories are much more accurate. If you take those inherent advantages of machine intelligence and combine them with what are today advantages of human intelligence—our pattern-recognition capabilities and the tremendous breadth and subtlety of our intelligence—that's a very formidable combination.

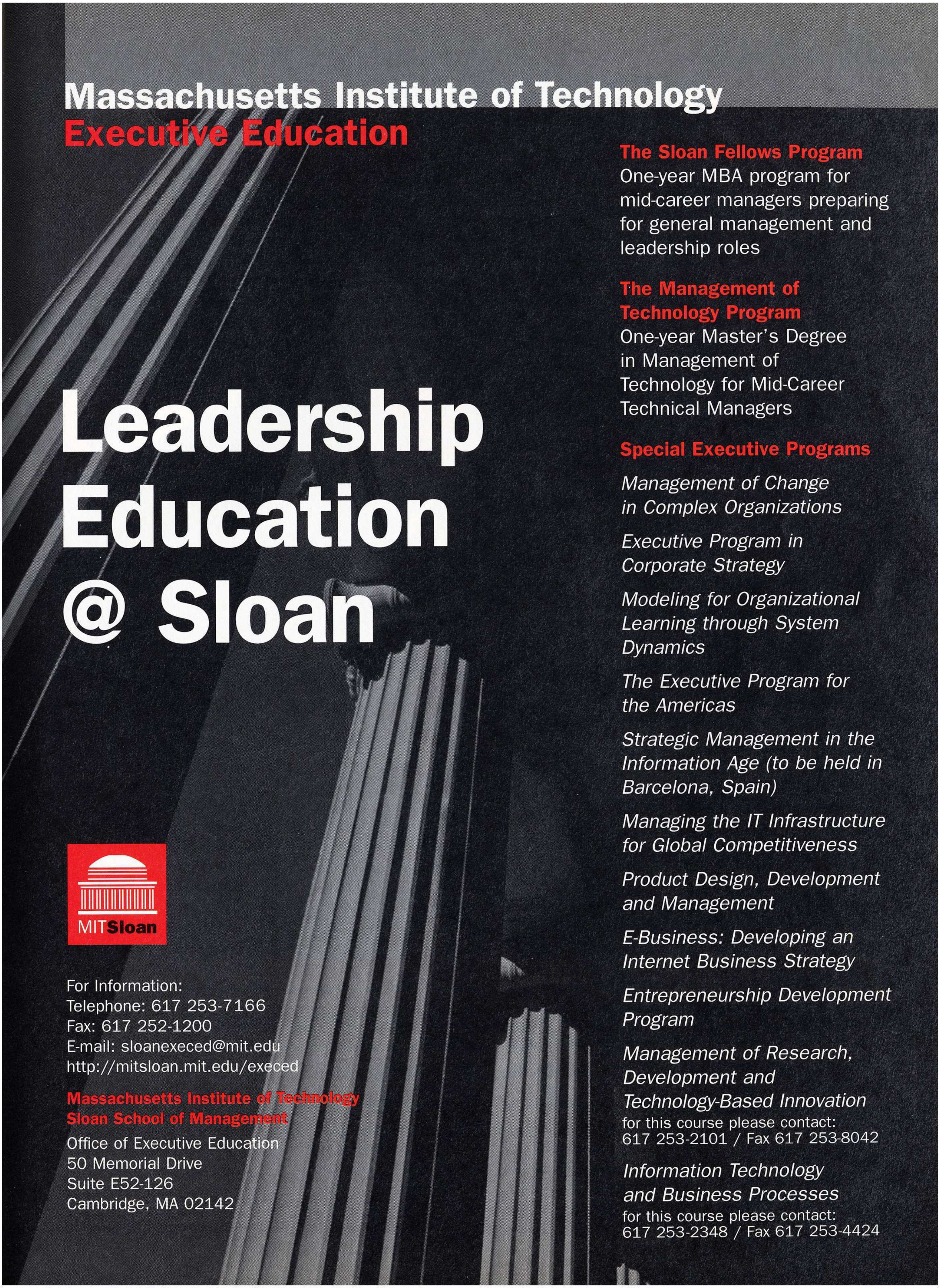
Technological progress is an extension of evolution and an economic imperative, Kurzweil says. Like it or not, competition will drive the whole process forward.

TR: Do you look forward to the future that you envision?

KURZWEIL: I do. I hope to be around working on it. I'm still on the first bridge to immortality, which is trying to take care of my biological body and brain in the old-fashioned way. I do think there are dangers, and the story of the 21st century hasn't been written. We have to create the next stage in evolution and infuse it with human values—not that we have a consensus of what those are.

TR: Will you be one of the first to make the jump and say good-bye to your squishy body?

KURZWEIL: It's a difficult question. You could scan my brain while I'm sleeping and recreate this new nonbiological Ray Kurzweil, which could come to me in the morning and say, "Hey Ray, good news. We've successfully copied and reinstantiated your brain and body, we don't need your old brain and body anymore." I might see some flaw in that philosophical perspective. I'll wish the new Ray well and I'll probably end up being jealous of him because he'll be able to succeed in endeavors I could only dream of, but I'm still here in my old biological body and brain. It's not clear how one gets over that divide to the other side—I haven't quite figured that out yet, but I do hope to see the era. ◊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A Death in Philadelphia

As many would-be biotech entrepreneurs have learned, one of the scariest things about bringing a new biomedical technology into the world is when an unexpected and very public problem crops up, especially during clinical trials. You can't tell if you've merely hit a bump in the road or run smack into a brick wall. At the moment of impact, they feel much the same.

The road to gene therapy, which has been nothing if not rocky over the last two decades, hit another one of those sickening bumps last September, when word spread from Philadelphia that a fatality had occurred in a gene therapy trial at the University of Pennsylvania's Institute for Human Gene Therapy. Eighteen-year-old Jesse Gelsinger, according to university officials, died four days after receiving experimental treatment for a genetic disorder known as ornithine transcarbamylase (OTC) deficiency. In reporting the episode, publications like the *Wall Street Journal* suggested that the death was "raising new questions" about a beleaguered technology.

When a young man died recently in a clinical trial, did gene therapy hit a speed bump? Or a brick wall?

As readers of my book *A Commotion in the Blood* already know, I've cast a pretty jaundiced eye on the extraordinary hype and the extraordinarily unimpressive results that have come out of this area of research so far. The field's pioneering practitioners seemed at least as interested in making history as in making patients better when the first authorized attempt at gene transfer occurred at the National Institutes of Health in 1989; more than a decade later, after hundreds of clinical trials, there has yet to be published a single study that unambiguously demonstrates gene therapy works. It is typical of the headlong (or is it headstrong?) ambition of the field that we now learn of other deaths in clinical trials, which went unreported to the NIH at the discretion of the investigators (many of whom relinquish the moral high ground when they have financial interests in the work).

For all that, this technology has immense intuitive appeal. The idea of turning engineered viruses into biological smugglers, using their evolutionarily honed ability to infiltrate cells and insinuate therapeutic DNA into the cell's chromosome, strikes almost everyone as an elegant and supremely clever way to correct enzymatic deficiencies and other genetic diseases. Indeed, the swelling list of genes identified by the Human Genome Project provides an attractive list of potential cargo for these viral vectors to deliver.

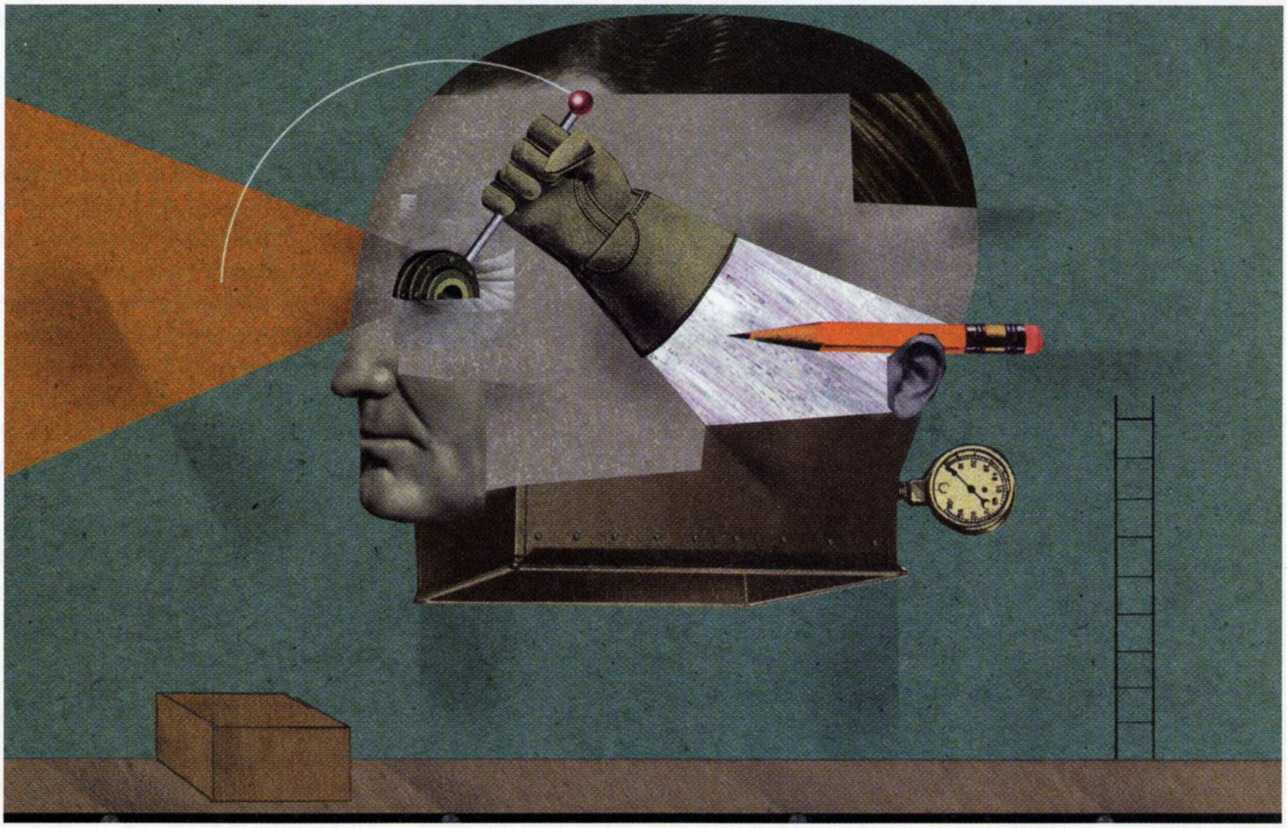
For a more general perspective, there was only one expert whose views I was interested in: Theodore Friedmann, professor of pediatrics, biomedical ethicist and director of the gene therapy program at the University of California, San Diego. Over the last two decades, Friedmann has worked on the science, charted the hype and chastised journalists and headline writers. He has also perfected the long view, in an age when even scientists who should know better seem hellbent on instant gratification. "At worst, I think it's another pothole in the road," he said from San Diego. "There is no question in any reasonable person's mind that the overall approach makes sense and is going to pay off in the future in the clinical treatment of disease. It's beyond retrieval. It's born, and it can't be unborn."

It might sound cold to liken a death to a pothole, but Friedmann refused to play the Claude Raines role here and profess shock—Shock!—that such a thing could occur. "Things happen," he said, "That's why it's called research. We don't know what's going to happen. And, in general, it's not a surprise that these kinds of things will happen." Despite those legalese disclaimers warning of uncertainty and risk on company prospectuses, the day-to-day syntax of biotechnology, the inflection in the voices that promote it, the body language of

its enthusiasts, is all inevitability: We *will* insert these genes, we *will* engineer these viral vectors, we *will* slam them in and we *will* get them to work, doing what we want and where we want. But science, especially cutting-edge science, remains steadfastly unpersuaded by imperative entrepreneurial verbs. Just last June, Phillip A. Sharp, a director at Biogen, spoke glowingly about a new drug in the pipeline called Antova, which was in advanced clinical trials; in October, Biogen halted clinical trials because of unexpected side effects.

Things happen, including deaths. Horrified as the biomedical research community was over the death of this bright and courageous young patient at Penn, fatalities are going to be part of the equation of progress in this business. They will often be unexpected and they will always be shocking, but they are, unfortunately, the price of admission to 21st century medicine. One hopes the field honors Jesse Gelsinger's death as it would any unexpected observation in an experiment: as an opportunity to learn something new, and perhaps something important, about the way nature works. And one hopes that the failure of some investigators to be forthcoming about *all* their data will not mortally compromise the future of gene therapy precisely when it seems poised to hit smoother pavement.

"By and large, the trajectory of gene therapy is still correct," Friedmann said. "Within a year or so, there will probably be the first credible, believable clinical results. Perhaps that will be ballyhooed, too. But at least then we'll know that there's a There there." ◊



DAVID PLUNKERT

VIEWPOINT | BY EAMONN FINGLETON

The Unmaking of Americans

Does our move from manufacturing to e-commerce spell ruin?

IN RECENT DECADES IT HAS BECOME increasingly fashionable for American opinion leaders to belittle the economic importance of manufacturing. If we are to believe such prophets of the New Economy as commentator Michael Rothschild and *Megatrends* author John Naisbitt, manufacturing is now a distinctly second-rate activity that should take a backseat to post-industrial businesses like software writing and moviemaking. Their opinions are increasingly endorsed by pundits in everything from the *Wall Street Journal* to *Wired*.

It is time this view was challenged. The truth is, it is a highly dangerous myth that is rapidly weakening the United States' ability to lead the world economy. Not only do those who advocate post-industrialism—let's call them post-industrialists—overestimate the prospects for information-based products and services, they greatly underestimate the prospects for manufacturing.

When the post-industrialists talk about manufacturing, it is clear they are referring mainly to such unsophisticated activities as the snap-together assembly work carried out in the television-set factories of the developing world. By implicitly defining manufacturing in such disparaging terms, they set up a straw man—for there is no question that, in an increasingly integrated world economy, most types of assembly work are so labor-intensive that they can no longer be conducted profitably in high-wage nations like the United States. Overlooked by the post-industrialists, however, is the fact that assembly is only the final stage in the production of modern consumer goods. Earlier stages are typically much more sophisticated—the making of advanced components such as laser diodes, liquid crystal displays, lithium-ion batteries and flash memories, for example. Then there is the production of the high-tech materials that go into such components. Semiconductor-grade silicon manufacturing, for instance, is concentrated mainly in such high-wage nations as

Japan and Germany. And still more sophisticated than the fabrication of such components and materials is the manufacture of the production machinery used in the process. Perhaps the iconic example of such machinery is the stepper—the highly precise lithographic device that prints circuit lines on silicon chips.

Manufacturing components, materials and production machinery is generally both know-how-intensive and capital-intensive. As such it can be conducted effectively only in the world's richest and most advanced economies—and workers engaged in such work are thereby shielded from low-wage competition from developing nations. The United States once dominated this type of production, but these days, as is abundantly clear from the nation's mounting trade deficits with Japan and Germany, it is at best an also-ran. In steppers, for instance, GCA, the once world-beating American player, closed its doors in 1993, leaving the field almost entirely to Japan's Nikon and Canon and Europe's ASM. In high-tech materials, the United States is now similarly dependent on imports. And in crucial new components such as laser diodes and liquid crystal displays, the country was never a contender in the first place.

Why does all this matter? Because, conventional wisdom to the contrary, advanced manufacturing offers fundamental advantages over post-industrial services in building a rich and powerful economy.

Manufacturing's most obvious advantage is that it creates an excellent range of jobs. Whereas post-industrial businesses like software and financial services tend to recruit mainly from the cream of the intellectual crop, manufacturing harnesses the skills of everyone from ordinary factory hands to the most brilliant scientists and the most capable managers. In fact, as the late Bennett Harrison of New York's New School (a longtime *TR* columnist) pointed out in his book *Lean and Mean* in 1997, unskilled workers "barely off the farm" can readily be trained to operate computer-controlled presses and similarly sophisticated production machinery. In Harrison's terms, today's high-tech production machinery is not "skill-demanding" but "skill-enabling."

Manufacturers also score over information businesses in their export prowess. That's because, for one thing, manufacturers usually avoid the piracy problems that so drastically reduce American information businesses' receipts from abroad. Moreover, manufactured goods are generally universal in application and, as such, contrast sharply with information-based products, which are in most cases quite culture-specific. Whereas a typical information product may have to be adapted for different languages and customs in different markets around the world, a typical manufactured product requires little if any adaptation. In many cases, information businesses don't find it worthwhile to adapt their products for foreign markets, and even where they do, they tend to have the adaptation done abroad, thus generating costs that cut deeply into the net revenues remitted to the United States.

Manufacturing creates an excellent range of jobs, generates large export revenues and—most important—high incomes.

A third key advantage of advanced manufacturing—the most important of all—is that it delivers higher incomes. Not only does the large amount of capital required for the enterprise offer workers protection against competition from cheap labor, it can also powerfully boost worker productivity. A good example is the contribution that expensive robots make in enabling Japanese auto workers to achieve the world's highest productivity levels. Higher productivity in turn is, of course, the royal road to higher wages.

Indeed, nearly two decades after the United States began its fateful drift into full-scale post-industrialism, international economic comparisons consistently show that Americans have lagged in income growth in the interim. The result is that, as measured at recent market exchange rates, the United States has now been overtaken in absolute wage levels by at least four manufacturing-oriented nations—Denmark, Sweden, Germany and, perhaps most surprisingly of all, Japan, the supposed "basket case" economy of the 1990s.

And if capital intensity is not enough to boost and protect wages, advanced manufacturing's requirement for proprietary production know-how gives many industry incumbents a critical advantage. Take a product like a notebook computer's flat-screen liquid crystal display. LCDs are basically an adaptation of semiconductor technology, and are manufactured using similar equipment. Thus in theory many computer companies around the world could enter this fast-growing business. But in practice few have done so, with the result that the world market is utterly dominated by a handful of Japanese manufacturers—Tokyo-based Sharp alone enjoys a world market share of close to 50 percent. Why such market concentration? The key is yield, the percentage of flaw-free products in each production batch. Given that even a microscopic speck of dust can render the tiny transistors that control each dot on a screen dysfunctional, the quality-control challenge is enormous. A new entrant to the industry would probably be lucky to get a 10 percent yield of good screens, whereas established Japanese firms are believed to achieve yields of 90 percent or more.

All in all, America's failure in the past two decades to take full advantage of manufacturing's numerous rewards is alarmingly apparent in the nation's deteriorating trade figures. The U.S. trade deficit in 1999 is likely to exceed $250 billion—an all-time record and an increase of about 50 percent on the startling $168.6 billion incurred in 1998. It would be an exaggeration to say that the nation's manufacturing decline is the sole cause of the worsening trade trend, but it is clearly one of the most important contributing factors.

And what is really worrying about these deficits is that they are to a large extent incurred with nations like Japan and Germany, where wages run 20 percent to 40 percent higher than American levels. Other things being equal, when a lower-wage country imports a product from a higher-wage one, we can reasonably assume that the manufacturing technology concerned is one in which the importing country is lacking. Much of

what American corporations import from higher-wage nations consists of components "outsourced" from foreign rivals. The U.S. firms got used to the practice in the 1970s and early 1980s when Japanese and German wages were still low by U.S. standards, and outsourcing components could be justified on the theory that it freed American workers to specialize in higher-level work. These days, however, American corporations that outsource to Japan or Germany are effectively admitting they lag in the technology race.

So what should the United States do to regain dominance in manufacturing? First, consider one of the key reasons for the country's loss of its leadership position: other nations' industrial policies, which almost always contain a strong element of explicit or implicit protection for home industries. The classic example is United States-Japan competition in electronics. While U.S. electronics manufacturers such as RCA and Zenith were largely barred from selling in the Japanese market, their Japanese competitors were welcomed with open arms in the American market—the inevitable result was that the Americans found it increasingly unprofitable to invest for the long term.

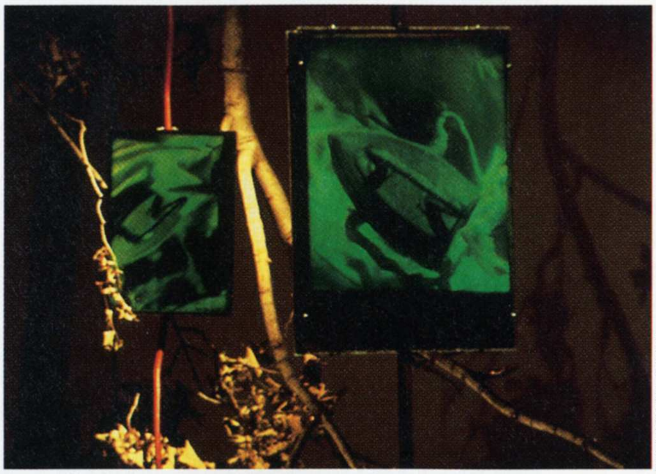
Though the party line these days is that such protectionism has largely been eliminated in key foreign markets, the reality is that other nations maintain industrial policies that put U.S. manufacturers at a disadvantage. For American decision-makers this creates an acute dilemma—and a particularly distressing one for today's 50-something power holders, who in their youth espoused the soaring hope that the world could be taught to sing in perfect harmony. If they cling to the idealistic One-Worldism of the Flower Power era, they will continue to advocate one-way free trade—and in the process will condemn the American manufacturing sector to, at best, permanent underdog status. The alternative is to slam the brakes on globalism and go back to the sort of modest but sufficient tariff levels that prevailed in the Eisenhower years. Such a move would certainly raise screams from devotees of that ultimate pseudo-science, laissez-faire economics. But in the absence of convincing alternatives (and in particular of a real commitment to free trade on the part of America's competitors), it must have a place on the agenda. TR

MIXED MEDIA

Has Holography Died Aborning?

This near-magical laser technology has become trinketware, and only one artist has really exploited its potential

A QUARTER-CENTURY AGO, holography threatened to become the next big thing in image-making: the cutting-edge medium that at last could give us a photographically credible illusion of three-dimensionality. Holograms, made under carefully controlled studio conditions by bouncing laser light off objects and displayed by a reversal of that process, emanated their images in an almost magical way. Things appeared to hover somewhere just out of reach, seemingly so real that you could walk around them.



THE DECORDOVA MUSEUM

Harriet Casdin-Silver works at the intersection between holography and sculpture, as in this multimedia depiction of an iron.

They weren't exactly like most other kinds of photographs (no lenses involved, for one thing), yet photographs—perhaps especially the one-of-a-kind images on sensitized metal plates named after Louis Jacques Mandé Daguerre—were their most obvious analogs and precedents. In any case, they were utterly marvelous. And this medium seemed to be the logical culmination of a powerful impulse to capture the world in all its dimensions.

Stereoscopic vision has interested both artists and scientists since the Renaissance, and detailed realistic representation traces back at least to the trompe-l'oeil paintings of the 16th century. With the advent of photography, 3-D imaging took a leap forward. The hand-held or table-model stereoscope and photographic stereo cards of the late 1800s remained commonplace household edutainment items through the early decades of this century. Subsequent inventions, periodically introduced, have kept such lens-based 3-D images before us recurrently as tantalizing options—the 3-D

INTERACTIVE ART

Digital Decay

You're browsing a friend's home page and a short text about mummification appears just under his name. Don't panic—it's art. You're experiencing *The Impermanence Agent*, devised by Noah Wardrip-Fruin, artist in residence at New York University's Media Research Lab. Wardrip-Fruin's work is one of two disturbing new interactive artworks that treat the themes of time and memory.

The Impermanence Agent appears as a small window with a scrolling story. The agent intercepts the Web pages you're browsing and uses text from your readings, over time, to modify the story. The Web pages you view also get altered. A funerary image might pop up in *The New York Times*. The banner title of *Arts and Letters Daily* might appear eroded or decayed, as if weathered by some electronic rain or television snow—all with the suggestion of the damage time does.

When a word from your own browsing appears in the scrolling text, it catches the eye. The story about impermanence is being wiped out by text from your own readings. This is art that runs in the background, while you're looking at other sites. So occasional grammatical failings are easily forgiven—you can simply appreciate those times when the result manages to trigger thoughts and provoke emotion.

The effacement of the scrolling story can also clue you in to what you've been reading online. After using *The Impermanence Agent* for a week, Wardrip-Fruin says, he asked himself: "Have I really been looking at technical articles all week?" Seeing the story entirely replaced with technical language made him "want to go read something from *Project Bartleby* or *WordCircuits*," online literary collections.

The Impermanence Agent embodies forgetting. Another piece of digital art treats a related theme. *[Phage]* demonstrates how things that have disappeared can resurface in unexpected and at times disconcerting ways, like repressed fantasies bubbling forth. Created by Mary Flanagan of the State University of New York at Buffalo, *[Phage]* scours a user's hard disk to find media fragments. Then it spins recovered text and images across the screen to the accompaniment of sound snippets, also pulled from the disk. Though named after a virus (the biological kind), this stand-alone PC program does not alter existing files on the hard disk, nor does it propagate itself without the user's consent.

Even if it's not infectious, *[Phage]* is dangerous; running this

movies and comic books of the post-World War II era, the Nimslo camera of the 1980s, even the Viewmaster with its little discs of paired images.

Yet none of these technologies ever became more than a fad or toy. Why? Photography, after all, has evolved consistently to encode an ever greater amount of information—and dimensionality is information of a crucial kind. But versatility, technical and economic accessibility, and reproducibility have been necessary accompaniments to each evolutionary step, and no photographic 3-D imaging system has ever combined all those qualities. Whichever lens-derived 3-D system possesses all those desirable qualities has a fair chance of catching on. And, if it does, just as color supplanted black and white, and print on paper supplanted the daguerreotype, eventually 3-D imaging will supplant 2-D imaging.

Many of us believed holography was that inevitable development. Yet no version of it, no matter how engaging, ever actually filled anything one could describe as a cultural need. Moreover, the technology remained cumbersome and esoteric, so the number of people with hands-on experience never expanded. And though a range of notable contemporary artists experimented with it, several of them—like Richard Kostelanetz—at some length, the medium failed to draw enough dedicated practitioners to achieve critical mass. Consequently, though many museums own a hologram or two, most people today know holography from credit cards, the occasional *National Geographic* cover or postage stamp, or else museum-shop paperweights and other tchotchkes rendering hokey still-lifes of skulls and watch gears.

In 1992, the Museum of Holography in New York City's SoHo closed its doors, due to lack of interest and shortage of funds. The museum's collection was preserved, but, though it's conceivable that some future generation may revive holography as an archaized, estheticized

NET NUGGETS

Hoaxbuster: Deadly spiders in the toilet? Long-distance charges for e-mail? Such alarms circulate endlessly on the Net. This site, maintained by Lawrence Livermore National Lab, sorts truth from fiction. **ciac.llnl.gov/ciac/CIACHoaxes.html**

The material world: Enter a set of attributes, such as melting point and density, and MatWeb tells you what materials match. Alternatively, enter a material and get a list of its properties. This database contains information—supplied by manufacturers and distributors—on more than 16,000 ceramics, metals and polymers. **www.matweb.com**

Searchers: The "Search Engine Showdown" maintained by Montana State University librarian Greg Notess compares all those Net-scouring tools. Notess has been called "the J.D. Powers of the search-engine world," and his site is authoritative and well-designed. **www.notess.com/search/**

User-hostile designs: Annoyed by counterintuitive software? The creators of the Interface Hall of Shame—an interface-design company called Isys Information Architects—share your pain. This site critiques the most infuriating instances of user-hostile design, with most cases drawn (surprise!) from Windows software. **www.iarchitect.com/mshame.htm**

software is like looking through old diaries. It's impossible to know what fragment of an old, emotionally charged e-mail (which you'd rather forget about) might fly across your screen, having been excavated from your hard disk.

Flanagan, whose other works in progress treat themes of women and work, notes that the piece has a different focus than typical interactive art. "In most software and interactive works," she says, "the story is not about you." *[Phage]*, like *The Impermanence Agent,* does make the story about you, by looking at content that you either selected or created. Unlike *The Impermanence Agent,* which by effacing one text with another reminds us of loss and forgetting, *[Phage]* can bring long-forgotten content from the hard disk back to light—reminding us that memory can sometimes be too persistent.

MARY FLANAGAN

[Phage] **fills your screen with disconcerting snippets from your hard drive.**

Both of these works forego the normal mousing and clicking for a more subtle—and highly effective—means of user influence. They both also pierce the "closed system"—the metaphorical museum—within which interactive art exists. They take the user's readings and writings and turn them into the art supplies of an automaton. Even with no or limited "intelligence," these compositors can provide a rare glimpse into the turbulent unconscious of our computers—our prosthetic minds.

The Impermanence Agent *can be experienced at www.cat.nyu.edu/agent/.* [Phage] *can be downloaded from www.fireantdesign.com/mary/virus.htm. Both works were exhibited at Digital Arts and Culture '99, a conference held late last year at Georgia Tech.*

—Nick Montfort

practice, it's hard to imagine anyone deciding to inaugurate a new institution devoted to this medium. So holography may end up as a curiosity from picture-making's past—without a genuine heyday of its own, a quirky production method for illusionistic artifacts replaced by some lens-based version of virtual reality. Or it may prove to be the true precursor of the 3-D imaging systems envisioned in our sci-fi, the conceptual stepping-stone between analog photography and its electronic descendants.

These are not mutually exclusive options. But whichever way it goes, the work of Harriet Casdin-Silver will require acknowledgment. For, even if holography turns out to be a technological sidetrack,

EDUCATION

The Playful Society


BARRY HETHERINGTON

Toys teach kids to tinker.

A good kindergarten fosters the spirit of learning by giving children materials, time and control over what they make. Some educators and media researchers are working to replicate this spirit of curiosity-driven tinkering in all classrooms, allowing students of diverse ages to explore and invent. The notion is that technological contraptions should be the material objects that replace finger paints and modeling clay in a logical but playful progression from kindergarten to university. This notion was on display at "Mindfest," a recent conference on learning technologies held at MIT's Media Laboratory.

Take Mindstorms, the programmable Lego bricks and sensors that allow kids to concoct mechanized and automated inventions. The hope is that children will combine these programmable blocks (called "crickets") with ordinary Lego blocks and other materials to compose playful, creative multimedia projects. At Mindfest, grade school student Kayty Himelstein attached a programmable cricket with a touch sensor to her bird feeder to create a program that counted birds landing on the feeder. She put up flags to see if birds were attracted to particular colors and compiled all of her data—for fun.

The conference showcased another technology that might help kids tinker: a small, hand-held computer called a visual memory unit (VMU) that comes with Sega's new Dreamcast videogame console. These include a small screen, control buttons, connector pins, and gobs of memory. Kids can save information from video games and copy and trade files with friends and playmates. But put the VMU in a different context, and its ability to store opens up possibilities to create interactive computer fun.

New learning styles will require not just clever gadgets but new pedagogical philosophies. The "Beyond Black Boxes" initiative, for instance, under Media Lab researcher Mitchel Resnick, starts from the concern that much advanced science and technology is becoming so abstract that children (and many adults, for that matter) find it increasingly difficult to see any connection to the physical world. The goal of this program is to develop a kit of computational tools with which kids can build their own simple scientific instruments, helping them to conceptually understand the inner-workings of technological inventions. The kit itself is still under construction.

Resnick believes kids stumble on new ideas when building their own material objects, but that, to be effective, the process must be pleasurable. "We need to think about computers not just as access to information," he says, but also as tools that can "support the emergence of a playful society."

—Rebecca Dorr

she has produced a durable body of work. A recent retrospective of Casdin-Silver's holograms at the DeCordova Museum and Sculpture Park in Lincoln, Mass., demonstrated that this medium, though difficult, nonetheless permits the artist to move through a complex technology into the poetics of space; it made me wish that more artists had chosen to exploit holography's potential.

For while more than a few artists have tried their hands at making a hologram or two, Casdin-Silver has made a life's work of it, and much of her success comes from the thinking in this form that resulted from such immersion. Not that she's a strict formalist; this work deals directly and recurrently with issues of gender, aging and sexuality, sometimes all at once. Its technological uniqueness appears not only to entrance audiences but also allow them to engage with these controversial issues. On two different occasions at the DeCordova, I watched museum-goers meet this 73-year-old grandmother's larger-than-life-sized, unabashedly erotic nude self-portrait, "70+1+2," on its own terms: with humor, excitement and joy. Casdin-Silver's work does not hide behind the complexity of its execution; instead, it uses its fascinating form to engage the viewer with its content.

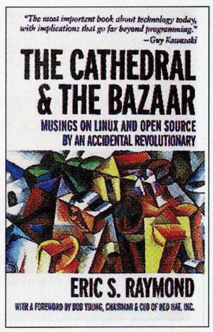
This piece, and the exhibition designed around it, made thoughtful use of the DeCordova's versatile spaces. The show included a few of Casdin-Silver's early paintings and graphics, as well as several mixed-media pieces and a reconstruction of her pre-holography 1968 installation, "Exhaust." What these make clear is that once this artist embraced technology, she never looked back. Her holograms, mixed-media installations incorporating holograms, and combinations of holograms with photographs consider the body and engage the senses, operating at the intersection between photography and sculpture. Some as yet undiscovered medium is bound to operate at this boundary. Whenever it does, Casdin-Silver's germinal body of work will demand acknowledgment. Perhaps holography's most enduring legacy will prove to be that it served at least one serious artist as a primary vehicle while anticipating the form that will eventually fulfill what holography only promised.

— A. D. Coleman

PAGES | BY WADE ROUSH

Software Frontier

THE CATHEDRAL AND THE BAZAAR
by Eric S. Raymond
O'Reilly & Associates, 268 pp., $19.95



IT WASN'T UNTIL FREDERICK Jackson Turner published *The Significance of the Frontier in American History* in 1893 that Americans fully realized there had been a frontier. In what was probably the most significant and controversial piece of scholarship of the 1890s, Turner showed that the nation's identity in the 19th century had hinged on westward expansion; now a new identity would be required.

"Open-source software" is another one of those concepts that gives historical unity to decades of bewildering change. The term didn't enter circulation until early 1998, but in the two years since, the revolutionary idea behind it has caught hold in boardrooms and IT departments across Silicon Valley and beyond.

That idea, first set out in writing by freelance programmer Eric Raymond in 1997, is that free software developed by large, informal networks of expert programmers—working not for money but for the respect of their peers—is usually more elegant and serviceable than "closed" or proprietary software sold for profit. The concept had been part of hacker culture for years, but Raymond provided the most accessible and precise formulation.

In *The Cathedral and the Bazaar*, a 1997 white paper circulated on the Internet, Raymond explained how the spread of the Linux operating system had crystallized his thinking. (The new hardcover by the same name contains the white paper and two related essays.) Linux is a free version of the Unix operating system, and was written by University of Helsinki student Linus Torvalds with a legion of collaborators starting in 1991 *(see "Programs to the People,"* TR *January/February 1999)*. From the start Torvalds made the source code available over the Internet. As users tinkered with it, discovered bugs, and suggested fixes, a global virtual community of Linux developers sprang up. The approach worked. Today, Linux is running on nearly one-sixth of business server computers and is gaining fast, largely at the expense of Microsoft's Windows NT.

Torvalds and his collaborators had set out to show that they could build a better operating system for free than IBM or Microsoft could with their billions. Some commentators explained their success as the result of the Internet's ability to nurture fluid working communities. But it took Raymond, who calls himself "the hacker culture's tribal historian and resident ethnographer," to recognize that this was only part of the story. He came to believe that Linux had succeeded by turning the traditional software development model—based on hierarchy, central planning and secrecy—on its head.

Before Linux, Raymond writes, "I believed that the most important software needed to be built like cathedrals, carefully crafted by individual wizards or small bands of mages working in splendid isolation, with not a beta release before its time." By contrast, the Linux community resembled "a great babbling bazaar of differing agendas and approaches." Linux's Internet archives were overflowing with versions of the system, and new releases appeared with alarming frequency. "Linus was treating his users as co-developers in the most effective possible way," Raymond concluded. "Release early. Release often. And listen to your customers."

As Raymond's conversion took hold, he realized that the open-source faith had been around long before Linux. Similar processes had given rise to some of the crucial parts of the global computing infrastructure, such as TCP/IP, the Internet's standard transmission protocol; SMTP for e-mail; and Apache, the software that powers more than 60 percent of Web servers. For hackers, Raymond says, building systems that benefit all is partly a form of play and partly a matter of prestige. Programmers volunteer to tackle complex problems because it's exhilarating to find a good solution, but also because turning that solution over to the community is a philanthropic act that reflects well on the giver. Properly guided by a winsome visionary like Torvalds, in Raymond's view, these forces can produce software that puts commercial products to shame. After all, open-source programs reflect the best efforts of the best minds, have been debugged by hundreds or thousands of reviewers—and they come with 24/7 "customer support" from the programming community.

"Factory software," by contrast, offers none of these advantages. "The closed-source approach allows you to collect rent from your secret bits, but it forecloses the possibility of truly independent peer review," Raymond writes. And worse: "When your key business processes are executed by opaque blocks of bits that you can't even see inside (let alone modify) *you have lost control of your business.*"

The threat that customers might take back control by choosing open-source software has become a serious worry for software giants. In the words of the famous Halloween Memo, an internal strategy document leaked from Microsoft in 1998, "Recent case studies provide very dramatic evidence...that commercial quality can be achieved/exceeded by OSS [open-source software] projects.... The free idea exchange in OSS has benefits that are not replicable with our current licensing model and therefore present a long-term developer mindshare threat."

Other companies are jumping on the bandwagon in order to avoid being run over. Raymond's white paper played a direct role, for example, in Netscape's decision in 1998 to make public the source code for its 5.0 Web browser. And while open-source software itself can't be sold for a profit, an important new industry is springing up to service it. Red Hat, a Linux-support company, watched its market capitalization soar into the billions shortly after its initial public offering last August.

Both as an overview of the open-source movement and as a case study in economic and cultural change, Ray-

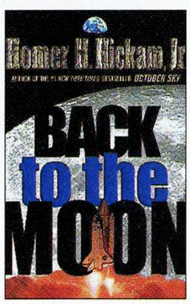
mond's book is a great read. The author is far from impartial, but he is realistic; he admits there are areas, such as office applications, where closed-source software is still appropriate. In the end, however, he believes that the entire computing infrastructure—operating systems, the Internet and communications software—will be open source, "cooperatively maintained by user consortia and by for-profit distribution/service outfits with a role like that of Red Hat." If that happens, *The Cathedral and the Bazaar* could well be remembered as the most important book on the software frontier of the 1990s.

Lunar Thrills

BACK TO THE MOON

by Homer H. Hickam, Jr.

Delacorte Press, 447 pp., $23.95



WHAT IF MERIWETHER Lewis and William Clark had returned to Virginia to describe the fabulous landscapes, exotic cultures, and abundant resources of the Louisiana Territory, only to have Congress cut off funding for future exploration west of the Mississippi, calling the enterprise a wasteful distraction?

The question is hypothetical, but Homer Hickam, Jr., feels that the U.S. government made that grave a mistake when it killed the Apollo program, confining all subsequent manned spaceflight to low-earth orbit. In his memoir *Rocket Boys*, Hickam recalled how his prize-winning high school rocketry project in 1957, the year of Sputnik, lifted him out of his native West Virginia coal-mining village into the ranks of NASA engineers. (The memoir was recently made into the successful film *October Sky*.) Considering how the space program transformed their lives, it's not surprising that Hickam and others of his generation at NASA feel betrayed by Apollo's cancellation.

To ease his frustration, Hickam has turned to fiction. *Back to the Moon* is a techno-thriller about Jack Medaris, a brilliant rocket scientist and obsessed widower who hijacks the space shuttle Columbia and flies it to the moon. Ostensibly he's searching for helium-3, a rare form of the element that could make nuclear fusion practical. Privately, he hopes to reconnect with his dead wife—exactly how, I won't give away. Hickam provides plenty of sex, violence, conspiracy and suspense to keep the story moving, but his real emphasis is on the technology.

He describes Medaris' daring plan for taking Columbia to the Moon in loving detail. It involves hiding an advanced rocket engine in the base of the shuttle's external tank, switching it on in orbit with the shuttle's main engine, blasting to the Moon, and landing beachball-style (as the Pathfinder mission did on Mars in 1997). The novel amounts to a proposal for a low-cost way to return to the Moon, using technology already within our grasp.

In an author's note, Hickam admits that he is mainly trying to show "what could be done with a little money and a lot of engineering guts." He complains that he and his contemporaries at NASA signed on to explore the Moon and planets but that the post-Apollo agency seems content to "carve endless loops around the earth in the space shuttle." Going back to the Moon today would be difficult, expensive and risky, Hickam admits, but he believes that the danger of not going—"a limited, painful future that won't allow spaceflight at all"—is even greater.

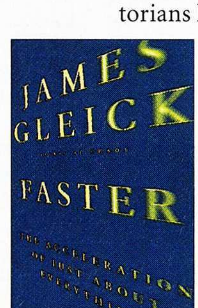
Like all good science fiction, *Back to the Moon* illuminates a question in the present through the lens of an imaginary future. Hickam asks whether we are adventurous enough to return where we once went "in peace, for all mankind." Meriwether Lewis would probably hope so.

Time, in Brief

FASTER: THE ACCELERATION OF JUST ABOUT EVERYTHING

by James Gleick

Pantheon Books, 324 pp., $24



LET'S CUT TO THE CHASE: *Faster* disappoints. James Gleick's *Chaos: Making a New Science* was a marvel of clarity and beauty, deserving its status as one of the best-selling popular science books of the last two decades. *Genius: The Life and Science of Richard Feynman* made a complex, elusive figure human, and contained just the right mix of physics and storytelling. So when I heard that Gleick was coming out with a book about time, I expected a serious exploration of time's role in relativity, or chronologists' quest for accuracy, or perhaps the neurology of time perception, leavened with character sketches and anecdotes and cultural references (all of which Gleick excels at). But *Faster* gives the leavening without the bread.

To be sure, what we get is tasty. Gleick has penned about three dozen bite-sized essays on everything amusing, ironic, manic or maddening about modern society's relationship with time, from the time-and-motion studies used by Henry Ford to speed up work on the factory floor to the origins of the odd phrase "real time" (as opposed to fake time?). You might not know, for example, that broadcast TV stations with multiple antennae use an atomic clock to keep the signals from getting out of sync and causing funny interference patterns on your screen, or that clock owners with accuracy fetishes complain to the Directorate of Time, the Defense Department agency that tends the nation's master clock, every time a leap second is inserted on New Year's Eve to compensate for the slowing of the Earth's rotation.

Gleick also shows how the modern obsession with "time-saving" techniques has altered many of our daily activities—in case you hadn't noticed—from breakfasts of microwaved Pop Tarts to bedtime stories condensed by one publisher into literary quickies that "can be read by a busy parent in only one minute."

This is all very stimulating. But like the remote-toting, attention-disordered TV audiences described in one of his chapters, Gleick doesn't alight long enough on any subject to give it depth. I would like to know what Gleick really thinks, for example, about how e-mail and instant messaging have changed the way people write, or what psychologists and social historians have to say about people's pervasive sense of time pressure. Could it be that we actually *like* living faster? If so, what does this mean for family life, for civic involvement, even for our spiritual selves? Gleick only hints at his, or anyone else's, learned opinions. Maybe he ran out of time.

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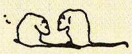

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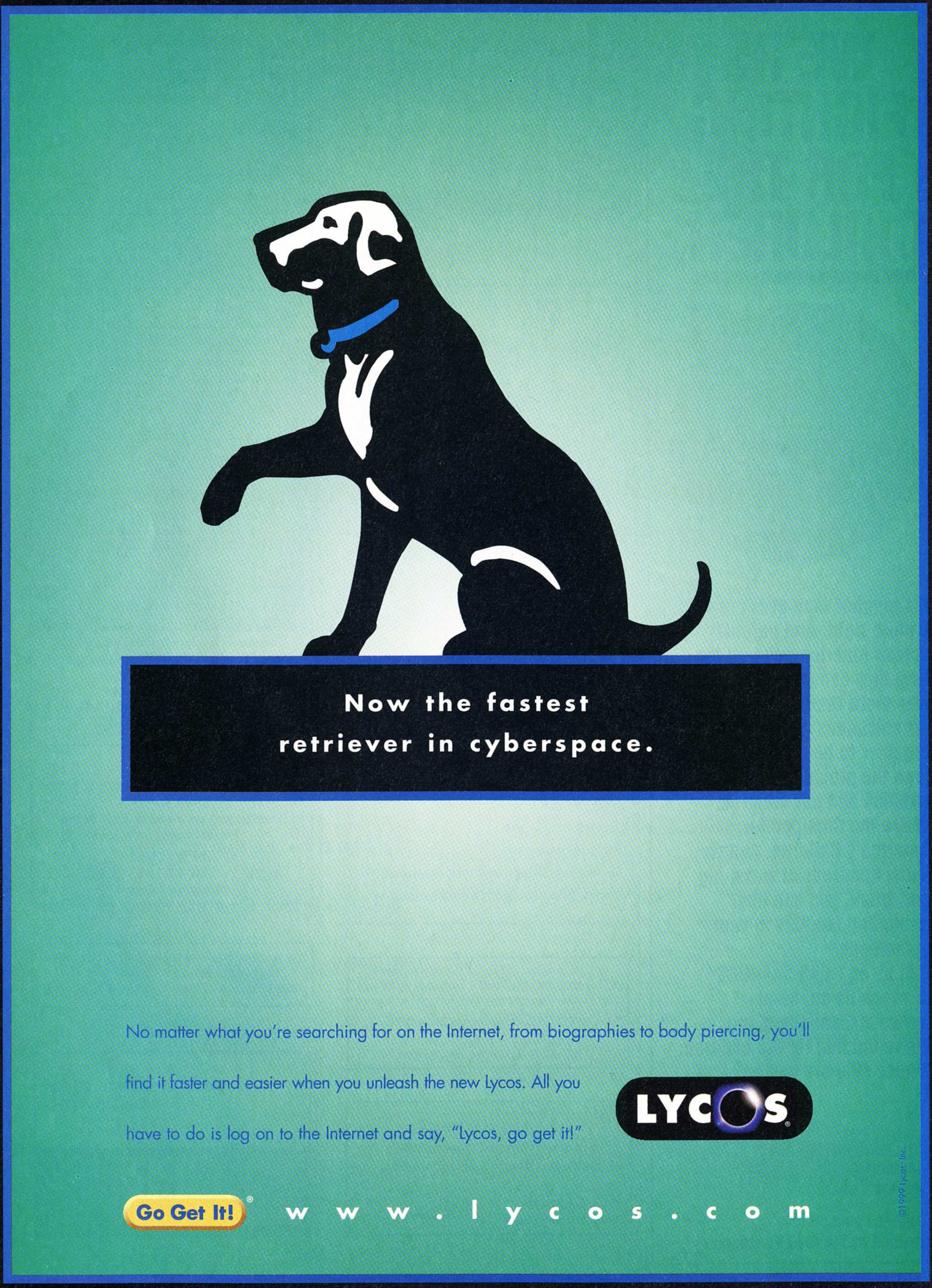
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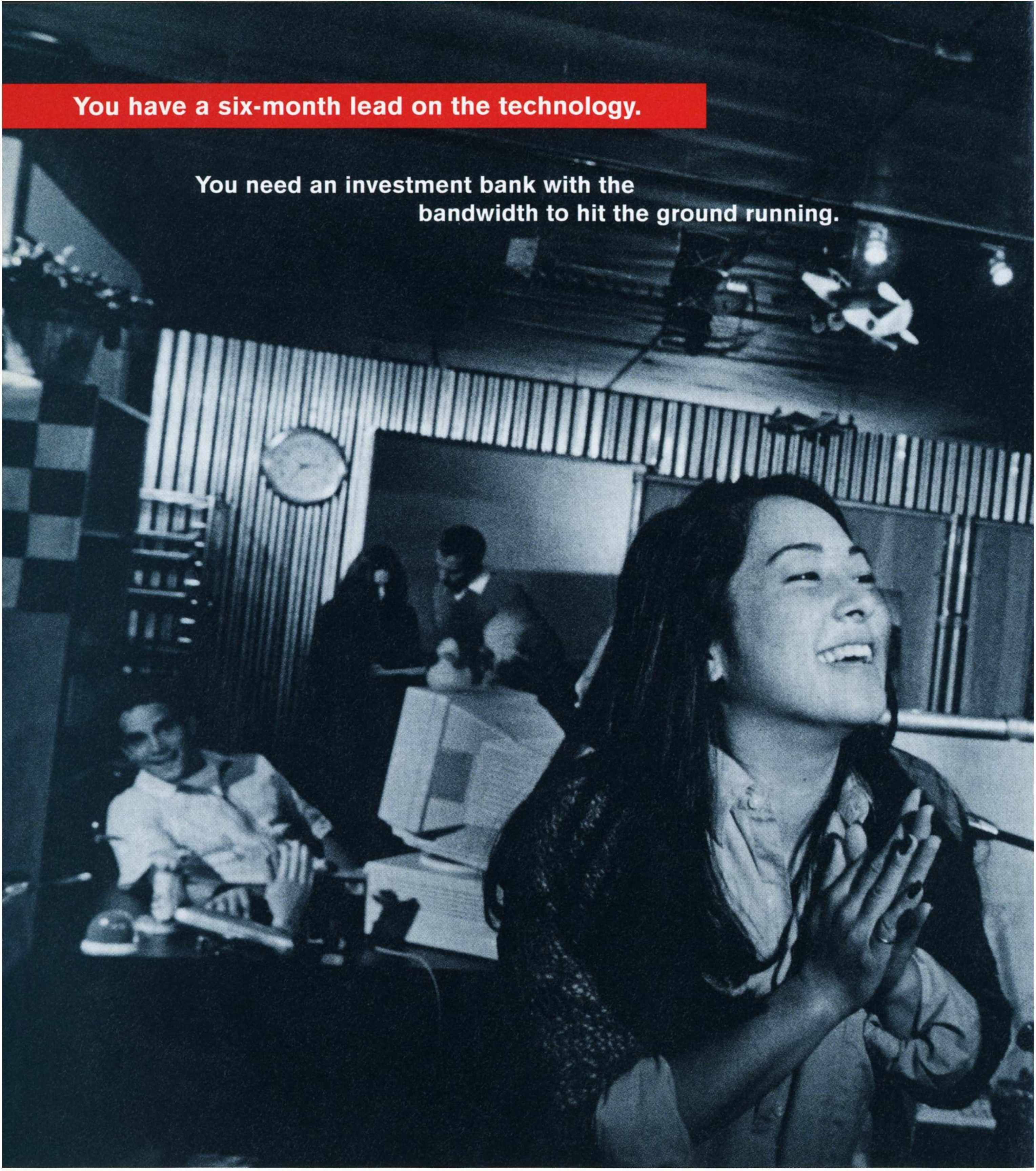

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No Operator, Please

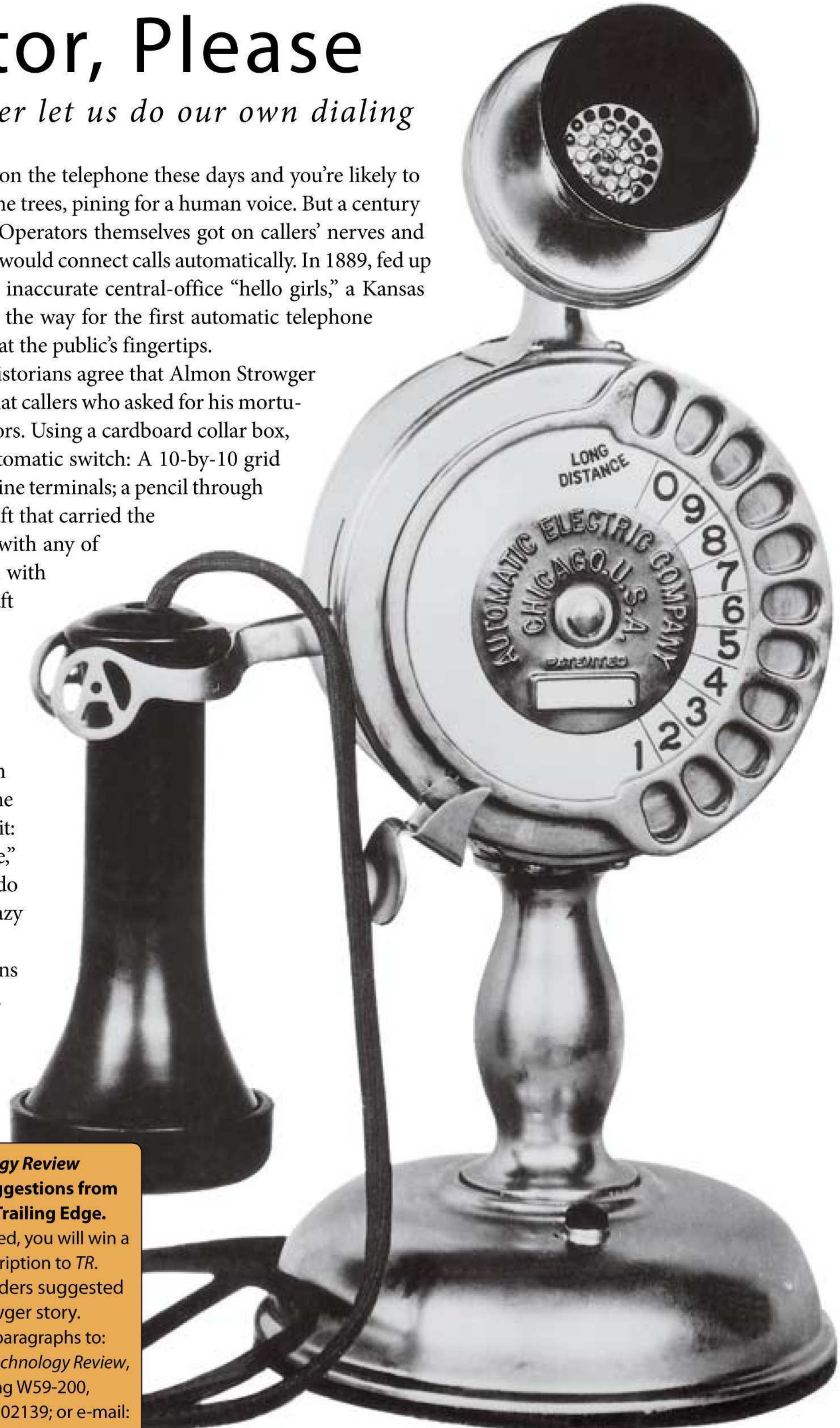
Almon Strowger let us do our own dialing

Try to get a real live operator on the telephone these days and you're likely to find yourself lost in a forest of phone trees, pining for a human voice. But a century ago, it was the other way around: Operators themselves got on callers' nerves and made them wish for a machine that would connect calls automatically. In 1889, fed up with the sometimes discourteous and inaccurate central-office "hello girls," a Kansas City undertaker filed a patent that paved the way for the first automatic telephone exchange and put the power of telephony at the public's fingertips.

The details are in dispute, but most historians agree that Almon Strowger was spurred into action by his suspicion that callers who asked for his mortuary were being connected to his competitors. Using a cardboard collar box, the undertaker built a prototype of an automatic switch: A 10-by-10 grid of pins stuck into the box represented 100 line terminals; a pencil through the box's center represented a rotating shaft that carried the caller's line and could bring it in contact with any of the others. The caller operated the switch with buttons on the phone which moved the shaft by row and column to align the correct terminals.

Strowger was issued his first patent in 1891. On November 3, 1892, he and his new business partners opened the Strowger Automatic Telephone Exchange in La Porte, Ind., using a modified version of the original switch concept. The system was a hit: "Besides giving cheaper and better service," crowed the *New York Tribune*, it would "do away with the sometimes impudent and lazy girls at the central station."

As automatic switching spread, the buttons were replaced with a finger-wheel dial. Strowger equipment, such as the 1905 dial phone, at right, was manufactured by the newly formed Automatic Electric Company. Strowger retired to Florida six years after he opened his first exchange, selling his patents for $1,800 and his stake in the company for $10,000. He died in 1902, and so the reputedly cantankerous inventor never knew what a bad deal he had made—in 1916 the Bell system licensed his invention for $2.5 million. ◊



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